0318081-SNY

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 338 864**
A2

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: 89304020.4

(51) Int. Cl.4: **G 11 B 11/10**

(22) Date of filing: 21.04.89

(30) Priority: 22.04.88 JP 99380/88
25.04.88 JP 102300/88
28.09.88 JP 243340/88
31.10.88 JP 275322/88
31.10.88 JP 275330/88

(43) Date of publication of application:
25.10.89 Bulletin 89/43

(84) Designated Contracting States: DE FR GB NL

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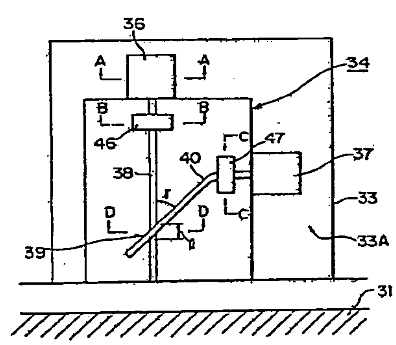
(54) Magneto-optical playback heads.

(57) A magnetic-optical playback head comprises a first optical waveguide (38) facing a light source (36) at one end thereof and facing a magneto-optical recording medium (31) at other end thereof for guiding an incident light beam to the recording medium (31), a second optical waveguide (40) for guiding a light beam reflected from the recording medium (31) to a photodetector (37) provided at one end thereof, a polarizer (46) for the first optical waveguide (38), and an analyzer (47) for the second optical waveguide (40), the polarizer (46) and the analyzer (47) being formed by providing first and second conductive layers (50, 51) on the first and second optical waveguides (38, 40), with first and second insulating buffer layers (48, 49) interposed therebetween.

FIG. 5



EP 0 338 864 A2

Description

MAGNETO-OPTICAL PLAYBACK HEADS

This invention relates to magneto-optical playback heads.

Figure 1 shows an example of a known optical head for a magneto-optical disc 1 forming a recording medium. A beam of light from a laser beam source 2 is passed through a grating 3, a lens system 4, a polarizer 5, a beam splitter 6, and an objective lens 7 to be converged on the magneto-optical recording disc 1. The return light beam reflected from the disc 1 is reflected by the beam splitter 6 into a direction at an angle of 90° with its original path, passed through a half-wave plate 8, and subjected to differential detection by means of a polarization beam splitter 9 and photodiodes 10 and 11, so that a playback signal is obtained. The reference numerals 12 and 13 denote cylindrical lenses.

Recently, there has been proposed a magneto-optical recording system for recording a signal by a magnetic-field modulation method, and capable of real-time over-writing using a single laser beam. That is, as shown in Figure 2, while a recording laser beam 18 is applied to one side of a magneto-optical disc 1 made up of a transparent substrate 15, a magneto-optical recording layer 16, and a protective layer 17, a magnetic head 21 mounted on a slider similar to a head for a magnetic disc is disposed to face the side of the disc 1 opposite to the side irradiated by the beam, and a signal to be recorded is supplied to the magnetic head 21. Playback is performed with a laser beam in the manner described with reference to Figure 1.

As an optical head for recording and playback, there has been proposed one using a branch type optical waveguide, in which the end of one branch waveguide is provided with a semiconductor laser as a light source, the end of the other branch waveguide is provided with a photodetector, and the end of the common waveguide is arranged to confront a recording medium, so that an emitted light beam from the semiconductor laser is lead through one branch waveguide and the common waveguide to impinge on the recording medium, and the reflected beam from the recording medium is guided from the end of the common waveguide to the other branch waveguide and allowed to enter the photodetector, and thereby, a playback signal is obtained (see Japanese laid-open patent specifications 60/59547, 60/59548 and 61/66238). An optical head has also been proposed which has a semiconductor laser and photodetectors, disposed at both sides thereof, integrally formed on a substrate, in which a light beam emitted from the semiconductor laser is applied to a recording medium and the reflected light therefrom is received by the photodetectors at both sides (see Japanese laid-open patent specification 62/192032).

In a magneto-optical recording system using a magnetic-field modulation method as shown in Figure 1 with an optical head arrangement shown in Figure 2 and a magnetic head 21 of a slider form, it is required that the objective lens 7 for converging the laser beam and the magnetic head 21 be driven at the same time, and therefore the mechanism becomes complex, making high-speed access difficult.

In a magnetic disc system using a thin-film magnetic head, high-speed access (20 ms) is achieved because a light-weight head fabricated by a thin-film technique or photolithography is used with a light-weight slider. However, the track density is limited to a maximum of 3000 TPI chiefly because of difficulty in connection with the signal level at the time of playback.

According to the present invention there is provided a magneto-optical playback head comprising:
a first optical waveguide facing a light source at one end thereof and facing a magneto-optical recording medium at another end thereof for guiding an incident light beam to said recording medium;
a second optical waveguide for guiding a light beam reflected from said recording medium to a photodetector provided at one end thereof;
a polarizer for said first optical waveguide; and
an analyzer for said second optical waveguide, said polarizer and said analyzer being formed by providing first and second conductive layers on said first and second optical waveguides, with first and second insulating buffer layers interposed therebetween, respectively.

According to the present invention there is also provided a magneto-optical playback head comprising:
a first optical waveguide coupled to a light source at one end thereof and facing a magneto-optical recording medium at another end thereof for guiding an incident light beam to said recording medium;
a second optical waveguide for guiding a reflected light beam from said recording medium, said second optical waveguide being formed of a first waveguide portion and a second waveguide portion, and one end of each of said first and second waveguide portions being provided with respective first and second photodetectors respectively;
a polarizer for said first optical waveguide; and
first and second analyzers for said first and second waveguide portions formed by providing first, second, and third conductive layers on said first optical waveguide and said first and second waveguide portions respectively, with insulating buffer layers interposed therebetween.

The invention will now be described by way of example with reference to the accompanying drawings, throughout which like parts are referred to by like references, and in which:

Figure 1 shows an example of a known optical head;

Figure 2 shows a magneto-optical recording system using magnetic-field modulation;

Figure 3 shows an embodiment of optical playback head according to the present inven-

tion applied to a light-weight slider;

Figure 4 is a perspective view showing an embodiment of optical playback head according to the present invention;

Figure 5 is a plan view of an embodiment of optical playback head according to the present invention;

Figures 6A to 6D are sectional views taken along lines A - A to D - D respectively in Figure 5;

Figure 7 shows an embodiment of recording and playback head according to the present invention;

Figure 8 is a perspective view showing another embodiment;

Figure 9 is an enlarged view in perspective of an end face of the optical playback head of Figure 8;

Figure 10A shows an Al-clad mode filter;

Figure 10B shows an amorphous Si-clad mode filter;

Figure 11A shows a polarizer formed of an Al-clad mode filter, and Figure 11B shows an analyzer formed of an Al-clad mode filter, the mode filters being used in combination;

Figure 12A shows a polarizer formed of an Al-clad mode filter, and Figure 12B shows an analyzer formed of an amorphous Si-clad mode filter, the mode filters being used in combination;

Figure 13 is a graph showing changes in optical outputs against angle α;

Figure 14 is a plan view showing an embodiment of an optical playback head according to the present invention;

Figures 15A to 15C are sectional views taken along lines A - A to C - C respectively in Figure 14;

Figures 16A1 and 16A2 are sectional views of first and second analyzers respectively;

Figure 16B1 shows magnetization recorded in a magnetic recording medium;

Figure 16B2 shows Kerr angles of rotation due to the magnetization in Figure 16B1;

Figures 16C1 and 16C2 show variations produced in optical outputs after being passed through the first and second analyzers, respectively;

Figures 16D1 and 16D2 show outputs of first and second photodetectors, respectively;

Figure 16E shows the output obtained differentially from the outputs of Figures 16D1 and 16D2;

Figures 17A1 and 17A2 are sectional views of first and second analyzers respectively;

Figure 17B1 shows magnetization recorded in a magnetic recording medium;

Figure 17B2 shows Kerr angles of rotation due to the magnetization in Figure 17B1;

Figures 17C1 and 17C2 shows variations produced in optical outputs after being passed through the first and second analyzers, respectively;

Figures 17D1 and 17D2 show outputs of first and second photodetectors, respectively;

Figure 17E shows the output obtained differentially from the outputs of Figures 17D1 and 17D2;

Figure 18 is a perspective view of an embodiment of recording and playback head according to the present invention on a slider;

Figure 19 is a sectional view of an embodiment of recording and playback head near its portion confronting the magnetic medium;

Figure 20 is an enlarged plan view of a magnetic recording head;

Figure 21 is a perspective view of an Si wafer for forming recording and playback heads;

Figures 22A1 to 22A6 are plan views for describing the process for forming recording and playback heads;

Figures 22B1 to 22B4 are sectional views taken along line B -B in Figures 22A1 to 22A4 respectively;

Figures 23A to 23F are diagrams for describing the process for fabricating a recording and playback head formed on a slider;

Figure 24 shows a light spot from an optical playback head;

Figure 25A shows light spots from optical playback heads;

Figure 25B shows playback optical outputs;

Figure 26 is frequency characteristics of playback outputs; and

Figures 27A and 27B are explanatory drawings of anisotropic etching of an Si substrate.

The present invention relates to a magneto-optical playback head for reading a signal from a magneto-optical recording medium making use of the magneto-optical effect.

The reading of a signal by magneto-optical effect makes use of rotation of the plane of polarization due to interaction between magnetization recorded in a magnetic medium and linearly polarized light. Media with a signal recorded therein in such a manner include magneto-optical discs in which recording is made, not using a bias magnetic field, but utilizing stray magnetic field in a medium heated by a laser beam, and those in which recording is made using a bias magnetic field, for example, an auxiliary magnetic field (dc magnetic field), and magnetic-field modulation.

The recording can also be performed by electromagnetic induction using a ring head or a single pole type head as described in detail below with reference to an embodiment of the invention.

An embodiment of optical playback head according to the present invention comprises a first optical waveguide, of which one end is provided with a light source and the other end is arranged to confront a recording medium, and a second optical waveguide, of which one end is provided with a photodetector, and further comprises metal-clad mode filters, which are formed by laminating conductive layers to the first and second optical waveguides with insulating layers interposed therebetween, the conductive layers being arranged at a predetermined angle to each other.

In the metal-clad mode filters, when the angle of inclination of the conductive layer of the metal-clad

filter (corresponding to a polarizer) formed on the first optical waveguide with respect to a reference plan is α, and the angle of inclination of the conductive layer of the metal-clad mode filter (corresponding to an analyzer) formed on the second optical waveguide with respect to the reference plane is β, it is preferred that they are arranged since that $\alpha + \beta = 45°$ or $\alpha + \beta \cong 45°$, which includes the case where $\alpha = 0°$ and $\beta = 45°$, or $\beta \cong 45°$.

Since, in the embodiments there are provided the metal-clad mode filters for the first optical waveguide and the second optical waveguide in such a way that they form a predetermined angle, that is, an angle of 45° or an angle close to 45° with each other, the playback signal can be maximized.

Moreover, since such an embodiment of playback head uses optical waveguides instead of a large lens system, and since the polarizer and the analyzer are formed by metal-clad mode filters, it is possible to mount the head on a light-weight slider.

Also, since the return light from the recording medium is split into two parts and the respective signals are read differentially, a signal twice as large as each is obtained, while dc components in the signals are suppressed or cancelled by each other, so that the signal-to-noise ratio (S/N) of the playback signal can be substantially improved.

Furthermore, since it is possible to arrange an electromagnetic induction type recording head and a magneto-optical playback head using optical waveguides, on a single slider, enabling it to operate the same as known flying heads for use with hard discs, access to the signal can be greatly improved.

Figures 3 to 5 as well as Figures 6A to 6D show an embodiment of optical playback head according to the present invention. Referring to Figure 3, there is shown a recording medium such as a magneto-optical disc 31, a recording track 32 thereon, and a light-weight slider 33, having on its end face 33A or 33B an optical playback head 34 according to this invention. The slider 33 has, for example, a width W of 3 mm and a height H of 1 mm, and is placed against the disc 31 by means of a gimbal mechanism exerting a required amount of pressure on the disc 31, that is, the slider 33 is attached to the free end of a resilient member 25. The slider 33 is, for example, fitted to a metallic plate 62 having a protrusion 61 on its top surface, so that the free end of the resilient member 25 comes into abutment with the protrusion 61, allowing the slider 33 to swing about the resilient member 25. The wiring from the head 34 is led out through a flexible wiring lead 79. The slider 33 can float over the medium 31 by means of an air flow produced by rotation of the disc 31, indicated by the arrow a. The optical playback head 34 is composed, as shown in Figures 4 and 5, of a semiconductor laser diode 36 (for example, a GaAs from junction laser diode) forming a light source, a photodetector 37 formed, for example, of a PIN photodiode or an avalanche photodiode, a first optical waveguide 38, of which one end is in contact or confrontation with the laser diode 36 and the other end is in confrontation with the disc 31, so that a beam of light emitted from the laser diode 36 is thrown directly on the surface of the disc 31, and a second optical waveguide 40, which is combined with the first optical waveguide 38 to form a cross type optical directional coupler 39, so that the beam of light reflected from the disc 31 is led from the first optical waveguide 38 to the photodetector 37 through the directional coupler 39, all these elements being disposed on a substrate 35.

The light emitted from the laser diode 36 is linearly polarized light having a plane of polarization in the direction parallel to its active layer, and its ratio of polarization indicating the degree of linear polarization is 80 to 100. Such a laser beam is introduced into the optical waveguide without experiencing mode conversion.

The first and second optical waveguides 38 and 40 are each formed, for example, of an ion-exchanged waveguide made of soda glass dipped in a solution of KNO_3 whereby K^+ ions are exchanged. More particularly, the first and second optical waveguides 38 and 40 are formed by being piled up and crossed with each other, that is, as shown in Figure 6D (a sectional view taken along line D - D in Figure 5), the first optical waveguide 38 is formed by an ion exchange technique on a sputtered glass film 43 on a soda glass substrate 42, another sputtered glass film 44 is formed thereon, and a second optical waveguide 40 is formed by the ion exchange technique on the sputtered glass film 44. In the present case, the width and depth of each optical waveguide 38 and 40 are adjusted so that a single mode may be obtained, namely, the electric field may be distributed as a Gaussian distribution within the optical waveguides 38 and 40. For example, when the refractive index of the substrate 42, and of the films 43 the 44 (CORNING 0211) is given as $n_s = 1.523$, the wavelength of the light $\lambda = 0.78\ \mu m$, the width of the end of the first optical waveguide 38 is $w = 5\ \mu m$, and the ratio of the width w of the end of the first optical waveguide 38 to the depth of diffusion d is $w/d = 2$, then, if the difference in the refractive indices Δn (= refractive index of the optical waveguide minus the refractive index of the substrate and films) satisfies the condition:

$$4.2 \times 10^{-3} < \Delta n < 9.8 \times 10^{-3}$$

the optical waveguides 38 and 40 become waveguides propagating the single mode. The first optical waveguide 38 is formed in a tapered optical waveguide, that is, it becomes thinner (its width W becomes smaller) towards its end where it confronts the magneto-optical disc 31. It can also be formed in an untapered, or straight, waveguide with a uniform width. The second optical waveguide 40, while it is arranged in confrontation or contact with the photodetector 37 at its one end, is closed on the way to the other end.

Meanwhile, although the laser diode 36 provides a linearly polarized beam having a sufficiently high ratio of polarization, there are disposed, in order to maximise the playback signal as described later, the metal-clad mode filters 46 and 47, serving respectively as a polarizer and an analyzer, for the first optical waveguide 38 midway between the laser diode 36 and the directional coupler 39, and for the second optical waveguide 40 midway between the

photodetector 37 and the directional coupler 39. As shown in Figure 6B (a sectional view taken along line B - B in Figure 5) and Figure 6C (a sectional view taken along line C - C in Figure 5), the metal-clad mode filters 46 and 47 are formed respectively by depositing conductive layers 50 and 51 made, for example, of Al over the first optical waveguide 38 and second optical waveguide 40 with buffer layers 48 and 49 of insulating layers made, for example, of SiO_2 interposed therebetween.

Moreover, the metal-clad mode filter 46 forming a polarizer and the metal-clad mode filter 47 forming an analyzer are arranged to form an angle of 45° or a predetermined angle close to 45° with each other. That is, for example, the metal-clad mode filter 46 is arranged so that its conductive layer 50 and buffer 48 are at an angle of α with a reference plane 52 (parallel to the substrate 42) as shown in Figure 6B, while the metal-clad mode filter 47 is arranged so that its conductive layer 51 and buffer layer 49 are at an angle of β with the reference plane 52 as shown in Figure 6C, and then $\alpha + \beta$ becomes $\alpha + \beta = 45°$ or $\alpha + \beta \cong 45°$. Here, by virtue of the formation of the conductive layers 50 and 51 over the optical waveguides 38 and 40, the metal-clad mode filters 46 and 47 transmit the TE mode therethrough and absorb the TM mode. In the metal-clad mode filter 46 forming a polarizer, it is preferred that the SiO_2 layer for the buffer layer 48 is formed with a thickness, for example, of 0.2 μm, so that the TE mode does not suffer a loss, and because the loss of the TM mode decreases as the film is made thicker.

The directional coupler 39 is coupled through the evanescent field. In the directional coupler 39, an angle of crossing γ of the optical waveguides 38 and 40 is preferred to be set to less than 1°. When $\gamma = 1°$, $w = 5$ μm, the space l at the crossing portion becomes approximately 600 μm.

Meanwhile, in the laser diode 36, as shown in Figure 6A (a sectional view taken along line A - A in Figure 5), the active layer 56 sandwiched between the p type clad layer 54 and then type clad layer 55 is arranged to be at an angle of inclination α the same as the angle of inclination α of the metal-clad mode filter 46 serving as a polarizer. As the laser diode 36, although not shown in Figure 4, one that is cut out such that its active layer is at an angle of α with the surface of the substrate 35 is used. Moreover, since the laser diode 36 is installed in the present example with an angle of inclination α in accordance with the angle of inclination α of the metal-clad mode filter 46, the first optical waveguide 38 is formed such that its surface 38a is also inclined at an angle of α along its entire length as shown in Figure 6D, and in addition thereto, the surface 40a of the second optical waveguide 40 at the directional coupler 39 is also formed to be inclined at an angle of α in parallel with the first optical waveguide 38. The second optical waveguide 40 is formed such that its surface 40a is inclined at an angle β at the metal-clad filter 47.

It is also possible to arrange that the laser diode 36 is not inclined, but the active layer 56 is held horizontal and to form the first and second optical waveguides 38 and 40 such that their surfaces 38a and 40a are held horizontal, whereas they are inclined at an angle α and angle β, respectively, at the metal-clad mode filters 46 and 47. In this case, however, the intensity of the light is lowered as compared with the example shown in the drawing. In the optical playback head of the described arrangement, a beam of light emitted from the laser diode 36 is introduced into the first optical waveguide 38, propagated through the metal-clad mode filter 46, and thrown on the surface of the disc 31. The plane of polarization of the reflected light from the disc 31 exhibits Kerr rotation, according to the directions of the recorded magnetization (for example, upward magnetization or downward magnetization) in the disc 31, of an angle of $+\theta$ or $-\theta$ with respect to the plane of polarization of the incident light. Since the spacing t between the end of the head and the disc 31 is less than 1 μm, the reflected light is introduced into the first optical waveguide 38 from its end, propagated to the second optical waveguide 40 through the directional coupler 39, and passed through a bent midway portion of the waveguide portion to be allowed to enter the metal-clad mode filter 47 forming an analyzer. Here, expressing the sum of the angle α and the angle β shown in Figure 6B and 6C as $\alpha + \beta = \varphi$, the change in the optical output after passing through the metal-clad mode filter 47 (at the Kerr rotation angle $\pm\theta$) is proportional to:

$$\cos^2(\varphi + \theta) - \cos^2(\varphi - \theta)$$
$$= -2\sin(2\varphi)\sin(\theta).$$

Hence, to make the change in the optical output a maximum, it is necessary to make $\varphi = 45°$ or thereabouts. For this reason, the conductive layers 50 and 51 and the buffer layers 48 and 49 of the metal-clad mode filters 46 and 47 are respectively given, as described above, the angles α and β, so that $\alpha + \beta = 45°$ or $\alpha + \beta \cong 45°$. It may also be practicable to arranged the metal-clad mode filters 46 and 47 such that their angles are $\alpha = 0$ and $\beta = 45°$ or $\beta \cong 45°$

The reflected light passed through the metal-clad mode filter 47 forming an analyzer is received by the photodetector 37 and subjected, for example, to differential detection, so that a playback signal is derived.

With the optical playback head, since the optical waveguides 38 and 40 are coupled through the directional coupler 39, so that the reflected light from the disc 31 is propagated to the second optical waveguide 40 by means of the directional coupler 39, mode conversion in which the direction of the plane of polarization is changed hardly occurs. Further, by the use of the directional coupler 39, the return light of the reflected light through the first optical waveguide 38 to the side of the laser diode 36 is limited, and thereby, oscillation of the laser diode 36 is prevented from being unstable.

In the present arrangement, since the metal-clad mode filters 46 and 47 are used for the polarizer and analyzer, and their buffer layers 48 and 49, and conductive layers 50 and 51 are arranged so that the angle formed therebetween may become 45° or close to 45°, the playback signal can be maximized.

Moreover, since the optical system can be made smaller than prior ones by the use of the optical

waveguides 38 and 40, the directional coupler 39, and the metal-clad mode filters 46 and 47 as described above, it can be formed on an end face 33A of a light-weight slider 33. Hence, high speed access and formation of narrower tracks can be attained.

Figure 7 shows an example of a magneto-optical recording and playback head utilizing the embodiment of optical playback head according to the present invention. This recording and playback head is for magnetic recording, by electromagnetic induction, and for optical playback, and is arranged to be capable of high-speed overwrite and high-speed access. Referring to Figure 7, a magneto-optical disc 71 is formed by laminating a reflecting film 73, a magneto-optical recording film 74, and a protective film 75 over a substrate 72, while an embodiment of magneto-optical recording and playback head 76 of the present invention is formed of a thin-film magnetic recording head 77 and an optical playback head 78 according to the present invention as described above placed side by side. The recording and playback head 76 is formed on and end face 33A of a light-weight slider 33 as shown in Figure 3. In the case of a magneto-optical disc having recording layers on both sides thereof, the light-weight sliders 33 with recording and playback heads 76 of the same structure mounted thereon may be disposed to confront both sides of the disc 71. The thin-film magnetic head is made of a magnetic thin-film of high magnetic permeability and high saturation magnetic flux density, and is structured as a magnetic circuit portion 80 in which a magnetic gap g is formed and a thin-film coiled conductor 81 is arranged to cross the magnetic circuit portion 80. The optical playback head 78 is made up of an optical waveguide 38, the second optical waveguide 40, and the cross type optical directional coupler 39 formed by both the optical waveguides 38 and 40, and has the first and second optical waveguides 38 and 40 provided with the metal-clad mode filters 46 and 47 forming a polarizer and an analyzer, the laser diode 36 as a light source, and the photodetector 37 formed of a photodiode. One end of the first optical waveguide 38 is arranged to confront the laser diode 36 and the other end is arranged to confront the disc 71. One end of the second optical waveguide 40 is arranged to confront the photodetector 37. Reference numeral 83 denotes wiring.

As the substrate 84 for forming the recording and playback head 76 thereon, an Si substrate may be used, and the photodiode service as the photodetector 37 may be formed in the Si substrate.

With this recording and playback head 76, recording with the thin-film magnetic head 77 effects overwrite recording into a narrow track of several µm at a high-speed of several tens to several hundreds of MHz possible. The arrangement of the optical playback head 78 formed of the optical waveguide element 82, the laser diode 36, and the photodetector 37 or photodiode permits the provision of miniaturized pick-up of a high S/N ratio. Further, the arrangement of the thin-film magnetic recording head 76 and the optical playback head 78 on a light-weight slider 79 eliminates the need for a lens system and focusing control, and provides a small-sized, light-weight magnetic recording/optical playback head. Furthermore, the use of the recording and playback head 76 for a disc 71 makes high-speed access, high-speed transfer, and a large-capacity disc drive attainable. It further supports a double-side medium magneto-optical disc, and therefore, double-side use of the disc as well as operation of a plurality of double-side recorded media on a common spindle in a stacked manner can be implemented.

The arrangement of the input and output optical waveguides also makes other arrangements possible such as use a branch type waveguide, or use a waveguide whose one end is provided with a laser diode, and another waveguide whose one end is provided with a photodetector, while the other ends thereof are juxtaposed close to each other facing a recording medium.

Figures 8 and 9 show another embodiment of an optical playback head. This optical playback head includes a first optical waveguide 38 whose one end confronts a laser 36 and the other end confronts a magneto-optical recording medium 31 and a second optical waveguide 40 whose one end confronts a photodetector 37 of a photodiode or the like and the other end confronts the magneto-optical recording medium. The end faces 38a and 40a of the first and second optical waveguides 38 and 40 confronting the magneto-optical recording medium are juxtaposed close to each other.

The first optical waveguide 38 is formed in a tapered optical waveguide, that is, it becomes thinner (its width W becomes smaller) towards its end 38a where it confronts the magneto-optical disc 31, so that it has a small sectional-area at the end 38a confronting the disc 31. The second optical waveguide 40 is formed so that it has a sectional area S_2 at its end 40a confronting the disc 31 larger than the sectional area S_1 at the end 38a of the first optical waveguide 38. In the present embodiment, the second optical waveguide 40 is formed to have a width W_2 larger than the width W_1 at the end 38a of the first optical waveguide 38. These optical waveguides may be formed of glass in which ions are exchanged as described above, or by selectively diffusing metallic ions of Ti or the like into a monocrystalline $LiTaO_3$ substrate.

In the middle positions of the first and second optical waveguides 38 and 40 are disposed metal-clad mode filters 46 and 47, serving as a polarizer and analyzer, respectively. As shown in Figures 6B and 6C, the metal-clad mode filters 46 and 47 are formed respectively by depositing conductive layers 50 and 51 of, for example, Al over the first optical waveguide 38 and second optical waveguide 40 with buffer layers 48 and 49 of insulating layers made, for example, of SiO_2 interposed therebetween. Moreover, the metal-clad mode filter 46 forming a polarizer and the metal-clad mode filter 47 forming an analyzer are arranged to form an angle of 45° or a predetermined angle close to 45° with each other. That is, for example, the metal-clad mode filter 46 forming a polarizer is arranged so that its conductive layer 50 and buffer layer 48 are at an angle of α with a

reference plane 52 (parallel to the substrate 42) as shown in Figure 6B, while the metal-clad mode filter 47 forming an analyzer is arranged so that its conductive layer 51 and buffer layer 49 are at an angle of β with the reference plane 52 as shown in Figure 6C, and then $\alpha + \beta$ becomes $\alpha + \beta = 45^0$ or $\alpha + \beta \cong 45°$.

In the optical playback pick-up of the described arrangement, a beam of light emitted from the laser diode 36 is introduced into the first optical waveguide 38, propagated through the metal-clad mode filter 46 forming a polarizer, and thrown on the surface of the disc 31. The plane of polarization of the reflected light from the disc 31 exhibits Kerr rotation of an angle of $+ \theta$ or $- \theta$ with respect to the plane of polarization of the incident light according to the directions of the recorded magnetization (for example, upward magnetization or downward magnetization) in the disc 31.

Then, the reflected light from the disc 31 is guided by the second optical waveguide 40 and passed through the metal-clad mode filter 47 forming an analyzer to be received by the photodetector 37 and subjected, for example, to differential detection so that a playback signal is derived.

By selecting the angles of the first and second mode filters with respect to the substrate to be as described above, the optical playback output can be maximized the same as in the case described above with reference to Figures 4 and Figure 5.

With the optical playback pick-up of the described arrangement, since the ends 38a and 40a of the first and second optical waveguides 38 and 40 confronting the disc 31 are disposed adjacent to each other, and further, the sectional area S_2 of the end 40a of the second optical waveguide 40 is formed to be larger than the sectional area S_1 of the end 38a of the first optical waveguide 38, it is possible effectively to collect the reflected light from the disc 31 and thereby achieve an improvement in the playback output. Moreover, since the sectional area S_1 of the end of the first optical waveguide 38 is made small, the return light quantity of the reflected light from the disc 31 to the first optical waveguide 38 is kept small, and hence, the laser diode 36 is prevented from making unstable oscillation affected by the return light. Further, since the first optical waveguide 38 is tapered and the sectional area S_1 of its end is formed to be smaller than that of the second optical waveguide 40, formation of a narrower recording track can be achieved.

Also, mode conversion causing the plane of polarization in each of the first and second optical waveguides 38 and 40 to change into a different direction is kept small.

Since the optical system can be constructed in a smaller size than prior ones by virtue of the above described arrangement using the optical waveguides 38 and 40 and the metal-clad mode filters 46 and 47, it can be formed on the end face 33A of a light-weight slider 33. Hence, high-speed access can be attained.

Now, an example in which the return light from a magneto-optical recording disc is split into two beams and the detected outputs from these are read differentially whereby increase in the output and improvement in the S/N ratio are obtained will be described.

To make the present example more understandable, optical output characteristics dependent on combinations of mode filters serving as the polarizer and analyzer will first be described with reference to Figures 10A, 10B, 11A, 12A, 12B and 13.

Figure 10A is a drawing a schematically showing an Al-clad mode filter, which is formed by putting an Al layer 108 on a optical waveguide 101 formed on a substrate 100, with a buffer layer 107 of SiO_2 or the like interposed therebetween. The Al-clad mode filter is the one which transmits the electric field component parallel to the Al layer 108, that is, a TE mode passing mode filter.

Meanwhile, Figure 10B is a drawing schematically showing an amorphous Si-clad mode filter, which is formed by putting an amorphous silicon layer 110 on a optical waveguide 101 formed on a substrate 100, with a buffer layer 109 of SiO_2 or the like interposed therebetween. The amorphous Si layer 110, that is, a TM mode passing mode filter.

In a optical playback head of the construction as shown in Figure 8 cases where constituents and angular arrangement of the polarizer 46 and analyzer 47 are changed in various ways will be considered.

An arrangement in which an Al-clad mode filter as shown in Figure 11A is used for the polarizer 46 and another Al-clad mode filter as shown in Figure 11B is used for the analyzer 47 is considered. If the angle α between the polarizer and analyzer is changed, the optical output at the photodetector 37 varies in accordance with $\cos^2 \alpha$ as shown by a curve C_1 in Figure 13.

In the above case, since the emitted light from the laser diode 36 is linearly polarized light having a plane of polarization parallel to the active layer, the Al-clad mode filter for the polarizer 46 has been arranged such that its Al layer is held parallel to the active layer of the laser diode, and, referenced from this direction, the angle α of the mode filter on the side of the analyzer 47 has been changed as shown in Figure 11B.

When such an arrangement is considered in which the Al-clad mode filter as shown in Figure 12A is used for the polarizer 46 and the amorphous Si-clad mode filter as shown in Figure 12B is used for the analyzer 47, the optical output at the photodetector 37 varies in accordance with $\sin^2 \alpha$ as shown by a curve C_2 in Figure 13.

In order to obtain a good S/N ration in practice, it is known that the angle α is preferred to be smaller than the maximum angle of 45°.

When the Al-clad mode filters only are used (Figures 11A and 11B), as apparent from the curve C_1 in Figure 13, a constant optical output, like a dc component, is produced within the range of $\alpha < 45°$ even when there is no change in the angle α, that is, when there is no change in the Kerr rotation angle. Since this dc component contributes to occurrence of noise when the optical playback signal is detected, it leads to deterioration in the S/N ratio. In contrast, when the Al-clad mode filter and the amorphous Si-clad mode filter are used in combina-

tion (Figures 12A and 12B), as apparent from the curve C_2 in Figure13, the dc component is kept small within the range of $\alpha < 45°$, and hence, a playback signal with a high S/N ratio can be detected.

Further, to take advantage of the optical output characteristics C_1 and C_2, differential detection may be implemented by providing two analyzers, and accordingly, providing two photodetectors.

Then, each of a combination of an Al-clad mode filter (TE mode) and an amorphous Si-clad mode filter (TM mode), a combination of an Al-clad mode filter (TE mode) and an Al-clad mode filter (TE mode), and a combination of an amorphous Si-clad mode filter (TM mode) and an amorphous Si-clad mode filter (TM mode) can be used for the two analyzers.

Preferred relations between the angles α_1 and α_2 of the two mode filters for each of the combinations are shown in the following table.

In this case, these angles are selected to be in such a relation that when the optical output from one photodetector increases (or decreases) against change in the Kerr rotation angle ($+ \theta$) on the magnetico-optical disc, the optical output from the other photodetector decreases (or increases).

TABLE

Mode Combination	Predetermined Angles (α_1, α_2)	
• TE mode (A1) and TE mode (A1)	①	$\alpha_1 + \alpha_2 = 180°$
• TE mode (amorphous Si) and TM mode (amorphous Si)	②	$\lvert\alpha_1 - \alpha_2\rvert = 90°$ (except the angles corresponding to ①)
• TE mode (A1) and TM mode (amorphous Si)	③	$\alpha_1 + \alpha_2 = 90°$ ($0 < \alpha_1 < 90°$, $0 < \alpha_2 < 90°$)
	④	$\alpha_1 + \alpha_2 = 270°$ ($90° < \alpha_1 < 180°$, $90° < \alpha_2 < 180°$)
	⑤	$\alpha_1 = \alpha_2$ (except the angles corresponding to ③, ④)

In the angular relations ①, ③ and ④ in the above table, the dc components being in phase are eliminated and twice as large an output as that of a single-end structure is obtained for the signal component.

In the angular relations ② and ⑤ in the table, while the dc components remain included to a certain degree, twice as large an output is obtained for the signal component.

Embodiments based upon the above described idea, will now be described.

The optical playback pick-up A, as shown in Figure 14, is made up of a semi-conductor laser diode (for example a GaAs P-N junction laser diode) 118 as a light source, first and second photodetectors 119 and 120 formed, for example, of a PIN photodiode or avalanche photodiode, and branch type optical waveguide 121 of a tree-like arrangement, all these elements being disposed on a substrate 114. The optical waveguide 121 has a first optical waveguide 121A, of which one end of $121a_1$ is in contact or confrontation with the laser diode 118 and the other end $121a_2$ is in confrontation with the magneto-optical disc 31, for throwing an emitted beam of light from the laser diode 118 directly on the surface of the disc 31, and a second optical waveguide 121B, which is branched from the first optical waveguide 121A at a position close to the other end $121a_2$ thereof, for guiding the reflected light from the surface of the disc 31 to the side of the first and second photodetectors 119 and 120. The second optical waveguide 121B is further branched so that optical waveguides $121B_1$ and $121B_2$ are extended to their respective ends $121b_1$ and $121b_2$, where the first and second photodetectors 119 and 120 are disposed confronting these ends.

Although the laser diode 118 provides a linearly polarized beam having a sufficiently high ratio of polarization, there are provided, to maximize the playback signal, a mode filter 123 forming a polarizer for the first optical waveguide 121A and first and second mode filters 124 and 125 forming first and second analyzers respectively for the second optical waveguide $121B_1$ and $121B_2$, disposed in their middle positions. As shown in Figures 15A, 15B, and 15C, these mode filters 123, 124 and 125 are formed respectively by depositing conductive layers 129, 130 and 131, for example, Al over the first optical waveguide 121A, one optical waveguide $121B_1$ and the other optical waveguide $121B_2$ of the second optical waveguide, with buffer layers 126, 127 and 128 made of an insulating layer of, for example, SiO_2 interposed therebetween.

Further, the first mode filter 124 forming the first analyzer and the second mode filter 125 forming the second analyzer are formed to be at predetermined angles α_1 and α_2, respectively, with the mode filter 123 forming a polarizer is formed to be parallel to a reference plane 1 corresponding to the active layer of the laser diode 118.

Reference numerals 132, 133 and 134 denote sputtered coatings of soda glass in the case where waveguides are formed by thermal ion exchange.

As the relation between the angles of inclination α_1 and α_2 of the first and second mode filters 124 and 125, that are shown in ① and ② in the above table can be selected.

Now, as an example corresponding to ① in the above table, the case where the predetermined angle α_1 for the first mode filter 124 is 135°, and the predetermined angle α_2 for the second mode filter 125 is 45° will be described with reference to Figure 16.

In this case, a beam of light emitted from the laser

diode 118 is introduced into the first optical waveguide 121A, propagated through the mode filter 123 forming a polarizer, and thrown on the surface of the recording track on the disc 31. The plane of polarization of the reflected light from the disc 31 exhibits Kerr rotation, according to the directions of the recorded magnetization (for example, upward magnetization or downward magnetization) in the disc 31, of an angle of $+\theta$ or $-\theta$ with respect to the plane of polarization of the incident light. The reflected light is guided by each of the second optical waveguides $121B_1$ and $121B_2$, and introduced into the first mode filter 124 (Figure 16A1) forming the first analyzer and the second mode filter 125 (Figure 16A2) forming the second analyzer respectively.

Since the first mode filter 124 is at the angle $\alpha_1 = 135°$ with the mode filter 123 forming a polarizer and the conductive layer 130 formed of Al or the like has a characteristic to transmit the TE mode and absorb the TM mode, the change in the optical output after being passed through the first mode filter 124 (at the Kerr rotation angle $\pm\theta$) becomes $\cos^2(135° \pm \theta)$. Likewise, it becomes $\cos^2(45° \pm \theta)$ with the second mode filter 125 at the angle of $\alpha_2 = 45°$.

Figure 16B2 shows changes in the Kerr rotation angle ($\pm \theta$) corresponding to the changes in the direction of the magnetization on the recording track surface 112 as shown in Figure 16B1. Figures 16C1 and 16C2 show changes in the optical output (the $\cos^2$ curves C_1) for the angles of inclination α_1 and α_2 of the first and the second mode filters 124 and 125, respectively, and Figures 16D1 and 16D2 show changes in the optical output in the first mode filter 124 and the second mode filter 125, respectively, caused by the changes in the Kerr rotation angle ($\pm\theta$) when $\alpha_1 = 135°$ and $\alpha_2 = 45°$, in accordance with the $\cos^2$ curves C_1 of Figure 16C, converted to electric signals ΔS_1 and ΔS_2 in the first and second photodetectors 119 and 120. From changes in these Figures 16D1 and 16D2, it is known that the changes in the optical output of the first mode filter 124 and the second mode filter 125 are 180° out of phase from each other.

Then, when the signals ΔS_1 and ΔS_2 are processed in a differential amplifier 135 to obtain the difference, the dc components being in phase are eliminated as shown in Figure 16E and an output signal 2S which is a combined signal of the signal components ΔS_1 and ΔS_2, being twice as large as each in magnitude, is obtained. Since the dc component is eliminated in this case, noise is not produced at the time of detection, and thus, the S/N ratio can be improved and reliable playback of the information (the direction of the magnetization) can be achieved. When the setting is $\alpha_1 = 135°$ and $\alpha_2 = 45°$ as in the present example the highest accuracy is obtained.

As another example corresponding to ① of the above table with both the first and the second analyzers 124 and 125 formed of Al-clad mode filters, selection is made such that $\alpha_1 = 145°$ and $\alpha_2 = 35°$. Then, by subjecting the signals ΔS_1 and ΔS_2 to the process for obtaining the difference in the differential amplifier 135 similarly to the above example, the dc components being in phase are eliminated, and an output signal 2S which is twice as large is obtained.

As an example of ② in the table, it is possible to set, for example, $\alpha_1 = 125°$ and $\alpha_2 = 35°$, when an output signal twice as large can be obtained although the dc component remains included to a certain degree.

Now referring to Figure 17, an embodiment in which an Al-clad mode filter (Figure 17A1) coated with an Al layer 130 is used for the first mode filter 124, and an amorphous Si-clad mode filter (Figure 17A2) coated with an amorphous Si layer 141 is used for the second mode filter 125 will be described.

As the conductive layer 129 for the mode filter 123 forming a polarizer, an Al layer is used the same as in the preceding embodiment.

In this case, the first mode filter 124 has the characteristic to transmit the TE mode and absorb the TM mode and conversely the second mode filter 125 has the characteristic to transmit the TM mode and absorb the TE mode. In this embodiment, as an exmaple corresponding to ③ in the table, it is set such that the first mode filter 124 forms an angle α_1 of 45° with the mode filter 123 as a polarizer and the second mode filter 125 forms an angle α_2 of 45° with the mode filter 123. The mode filter 123 is disposed to be parallel to the reference plane 1 the same as in the preceding embodiment.

The same as in the preceding embodiment, Figure 17B2 shows changes in the Kerr rotation angle ($\pm \theta$) corresponding to the changes in the direction of the magnetization along the recording track 112 shown in Figure 17B1, and Figure 17C1 and 17C2 show changes in the optical output (the $\cos^2$ curve C_1) for the angle of inclination α_1 of the first mode filter 124, and changes in the optical output (the $\sin^2$ curve C_2) for the angel of inclination α_2 of the second mode filter 125. Figure 17D1 and 17D2 show changes in the optical output in the first mode filter 124 and the second mode filter 125 caused by the changes in the Kerr rotation angle ($\pm \theta$) when $\alpha_1 = 45°$ and $\alpha_2 = 45°$, in accordance with the $\cos^2$ curve C_1 and the $\sin^2$ curve C_2 of Figures 17C1 and 17C2, converted to electric signals ΔS_1 and ΔS_2 in the first and second photodetectors 119 and 120. From changes therein, it is known, the same as in the preceding embodiment, that the changes in the optical outputs of the first mode filter 124 and the second mode filter 125 are 180° out of phase from each other. Hence, if the signals are subjected to detection in the differential amplifier 135, the dc components are eliminated while the signal component is doubled, and therefore, a playback signal can be detected at a high S/N ratio.

In another example corresponding to ③ of the table, with the first analyzer 124 formed of an Al-clad mode filter, and the second analyzer 125 formed of an amorphous Si-clad mode filter, and with the angles set such that $\alpha_1 = 35°$ and $\alpha_2 = 55°$, when the signals are processed by the differential amplifier 135 to obtain the difference, the dc components are eliminated and an output signal $\Delta 2S$ twice as large is obtained.

Further, in the case of either of the examples corresponding to ④ of the table where $\alpha_1 = \alpha_2 = 135°$ and $\alpha_1 = 145°$ and $\alpha_2 = 125°$, upon obtaining the difference in the differential amplifiers 135, the dc components are eliminated and an output signal Δ2S which is twice as large is obtained.

In an example corresponding to ⑤ of the table where setting is made such that $\alpha_1 = \alpha_2 = 40°$, by obtaining the difference in the differential amplifier 135, an output signal Δ2S twice as large is obtained although the dc component remains included to a certain degree.

It is also possible to use a combination of the first and the second mode filters 124 and 125, each being an amorphous Si-clad mode filter. In this case, the angles may be set according to ① or ② of the table as in the embodiment described first above. As examples of such angular arrangement, combinations of $\alpha_1 = 45°$ and $\alpha_2 = 135°$, $\alpha_1 = 145°$ and $\alpha_2 = 35°$, $\alpha_1 = 125°$ and $\alpha_2 = 35°$, and so on can be used. These combinations are just some examples of the possible combinations, and any combinations of the mode filters satisfying the conditions mentioned in the above table may be used, within the range of angles from which sufficiently high optical output variations can be obtained according to Δθ.

In the embodiment described second above, an amorphous Si-clad mode filter coated with the amorphous Si-clad mode filter coated with the amorphous Si layer 141 was used for the second mode filter 125. Although the amorphous Si layer normally has a characteristic to transmit the TM mode and absorb the TE mode, it is known that its transmitting mode will change as the thickness of the layer is changed, that is, it will become able to transmit either the TM mode or the TE mode (see The Transactions of the IEICE, Vol. E70, No. 4 April 1987, Letter [1987 Natl. Conv., March 26 - 29] Multilayer Waveguide Polarizer with a-Si:H film clad). Therefore, it is possible to form all the mode filters coated with the amorphous Si layer 141.

According to the above described embodiments, in either of the cases where the transmitting modes of the mode filters 124 and 125 as analyzers are the same and where the transmitting modes of the mode filters 124 and 125 are different, appropriate selections of the angle of inclination α_1 of the first mode filter 124 and the angle of inclination α_2 of the second mode filter 125 enables the changes in the optical output to be sensitively detected and, at the same time, the dc components as a cause of noise at the time of detection to be eliminated and, in contrast, the signal level to be doubled, so that a playback signal can be detected at a high S/N ratio.

Since the mode filter 123 forming a polarizer was arranged to be parallel to the reference plan 1, the laser diode 118 as the light source, specifically, its active layer, can be held parallel to the substrate 114, and thus, hybrid arrangement of it with the laser diode 118 can easily be achieved.

The arrangement of the first optical waveguide for throwing light on the medium and the second optical waveguide for guiding the output light may be as described with reference to Figure 4 or 8.

Now, an example of a recording and playback head formed by having a magnetic head for making a magnetic record in a magnetic-optical recording medium by electromagnetic induction, laminated over a portion of an optical playback head according to the present invention, will be described.

The recording and playback head is disposed on one end face 33B of the slider 33 shown in Figure 3.

A main portion of Figure 3 is shown in an enlarged schematic view of Figure 18, and a second view of it at the portion of the recording magnetic head taken along the direction in which the head moves relative to the medium is shown in Figure 19.

The recording and playback head, will be described in connection with its process of fabrication.

This head is joined to the substrate 221 having the recording and playback head mounted thereon such that the gap g of a thin-film magnetic recording head and one end of the optical waveguides of the optical playback head look out of the confronting plane 81, confronting the magneto-optical disc 31, on one side face of the slider 33.

The substrate 221 is, for example, cut out from a monocrystalline Si wafer 230. On the same, as shown in Figure 21, a plurality of laminated members 227 of the thin-film magnetic recording head and the optical playback head are simultaneously formed within each of rectangular head forming areas 228, which are arranged into a plurality of vertical columns and a plurality of horizontal rows.

Steps of the procedure for forming the thin-film magnetic heads and optical playback heads on the Si wafer 230 will be described below with reference to Figures 22A1 to 22A6 and Figures 22B1 to 22B4. Figures 22A1 to 22A6 schematically show enlarged plan views of the principal portion at each step of the formation and Figures 22B1 to 22B4 shown sectional views taken along line B - B in Figures 22A1 to 22A4.

First, as shown in Figures 22A1 and 22B1, first to third photodetector devices 231 to 233 are formed close to one short side 228a of each of the head forming areas 228 on the wafer 230 and fourth and fifth photodetector devices 234 and 235 are formed disposed in contact with and adjoining the long side 228c and closer to the short side 228b opposite to the short side 228a. These photodetector devices 231 to 235 are structured, for example, of a photodiode and all thereof are formed on the side of a principal plane 230a of the Si wafer 230 by a well-known technique. On the principal plane 230a of the wager 230, there is formed a surface insulating layer 236 of SiO_2 or the like by a method such as thermal oxidation of Si, and on this surface insulating layer 236, there are formed a required number of terminal areas 237 in an array towards the side of the other long side 228d for leading out external leads therefrom. At the same time, there is formed a die bonding pad portion 238 for die bonding a later described semiconductor laser at the position close to and confronted with the first photodetector device 231, and in the vicinity of it, there is formed a wire bonding pad portion 239 used for wire bonding one of the electrodes of the semiconductor laser. At the same time, there are formed wiring conductive

layers 240 for connecting one of the electrodes of the first to fifth photodetector devices 231 to 235 to their corresponding terminal areas 237 and those for connecting the die bonding pad portion 238, the wire bonding pad portion 239, and so on to their corresponding terminal areas 237. Such terminal areas 237, bonding pad portions 238 and 239, and the wiring conductive layers 240 can be simultaneously formed into required patterns by deposition of Al or the like over the whole surface, through techniques such as metallic evaporation sputtering, or etching by photolithography.

Then, as shown in Figures 22A2 and 22B2, first and second inclined planes 241A and 241B whose one ends are located at a position opposing the second and third photodetector devices 232 and 233 and stretched therefrom along the length of the long sides 228C and 228d. These first and second inclined planes 241A and 241B are formed to be inclined by 45° or so. These first and second inclined planes 241A and 241B can be formed, for example, by anisotropic etching of a monocrystalline silicon wafer 230.

In the case of monocrystalline Si, the planes which give the maximum value of the etching rate are the crystal planes (110), and those which give the minimum value are the crystal planes (111). If, for example, as shown in Figure 27A, an Si monocrystalline substrate 301 cut out along its crystal plane (100) is subjected to etching with a pyrocatechol ethylene diamine solution of aqueous solution of KOH using an etching mask 307 formed, for example, of SiO_2 and having a window 307a of a slit form elongated along the axis <100> (in the direction perpendicular to the drawing in Figure 27A), then, within a range of the width of the window 307a and the etching depth, an etching groove 308 of a triangular section as shown in Figure 27A is made, so that inclined planes 302A and 302B which are exposed crystal planes (111) each thereof forming an angle θ_1 of 54.74° with the surface of the substrate 301 are obtained on the side walls. Or, when, as shown in Figure 27B, an Si monocrystalline substrate 301 having the crystal plane (110) lying along the surface of the substrate 301 is subjected to similar anisotropic etching using an SiO_2 etching resist 307 having a window 307a of a slit form elongated along the axis <110>, then, according to selection of the width of the window 307a and the etching depth, an etching groove 308 with the crystal plane (110) exposed on the bottom face and the crystal plane $(11\bar{1})$ and $(\bar{1}\bar{1}\bar{1})$ exposed on both sides thereof is made, whereby inclined planes 302A and 302B each thereof forming an angle θ_2 of 35.26° with the surface of the substrate 301 are obtained. Therefore, by forming a pair of clad type mode filters on these inclined planes 302A and 302B, it is made possible to obtain a pair of clad type mode filters having a function of filtering the plane of polarization at an angle determined as required.

A GaAs substrate can also be employed making use of its anisotropic property exhibited in etching with a Br_2 methanol group etchant, in which the maximum etching rate is exhibited in the direction of the axis <110> and the minimum rate is exhibited in the direction of the axis <111>. In this case, by using a substrate having the crystal plane (100) and forming the etching pattern in the direction of the axis <110>, it is possible to obtain a groove with the first and second inclined planes provided on the crystal planes 111 forming an angle of about 45° with the surface of the substrate 301.

A wafer with its surface taken along the crystal plane (100) is used as the monocrystalline Si wafer 230 and the direction along the long side fo the area 228 is selected to be in the direction of the axis <100>. An insulating layer 242 of SiO_2 or the like is formed all over the surface of the wafer 230 by chemical vapour deposition or the like, and an elongated window 242A is made in this insulating layer 242 along the axis <110> by a photolithographic technique or the like. Through this elongated window 242A, etching is performed with an etchant such as KOH or a mixed solution of pyrocatechol and ethylene diamine. Then, since the crystal planes 110 exhibit the maximum etching rate and the planes (111) formed on both side faces thereof.

Then, as shown in Figures 22A3 and 22B3, an optical waveguide layer 223 forming the optical playback head is formed. The optical waveguide layer 223 is made up of a first optical waveguide 244, which is, first stretched from the midpoint between the fourth and fifth photodetector devices 234 and 235 in the direction parallel to the short side up to a bent portion, and then, stretched in the direction parallel to the long side until its end is led into a die bonding pad portion 238, and a second optical waveguide 245, of which one portion is a trunk 245C, one end thereof being located in the vicinity of or in contact with the end of the first optical waveguide 244 located between the photodetector devices 234 and 235, is similarly stretched in the direction parallel to the short side up to a bent portion, and stretched therefrom in the direction parallel to the long side to a point, where branches 245A and 245B are branched from the trunk, making a Y-shape, and these branches are stretched along the inclined planes 241A and 241B until their ends are led into the second and third photodetector devices 232 and 233, respectively. The optical waveguides 244 and 245 are formed, for example, by depositing an optical waveguide forming thin-film layer of soda glass or the like all over the wafer 230 including the interior of the groove 243 to a thickness of 5 to 10 µm, and then, by applying selective ion exchanging, for example, of K^+ for Na^+ in the soda glass at the portion of the layer where the optical waveguides 244 and 245 are to be formed, from the surface to a required depth, thereby providing the portion with higher refractive index. Such a process to form optical waveguides by ion exchanging is carried out, although not shown, by coating the entire surface with a high temperature resistant mask of polyimide or the like, further coating the surface with a film of SiO_2 or the like serving as a resist to reactive ion etching (RIE), making a window having a pattern of the optical waveguides 244 and 245 in the film with a photoresist, opening windows with RIE through the resist mask of SiO_2 or the like and the material layer

thereunder of polyimide or the like, and then dipping the wafer 230 in a molten liquid of KNO_3. Thus, ion exchanging with K^+ is achieved and the optical waveguides 244 and 245 are formed. Otherwise, such optical waveguides can be formed by carrying out selective ion implantation and diffusion as required, thereby providing the portion with a higher refractive index. Or, otherwise, by forming a thin film having a higher refractive index on the wafer 230 with a buffer layer of SiO_2 or the like interposed therebetween, and etching the film of high refractive index into a desired pattern by a photolithographic technique, ridge type optical waveguides formed of the film of high refractive index can be obtained.

As shown in Figures 22A4 and 22B4, the above described polyamide used as the mask for the ion exchanging of the surface of SiO_2 thereon used as the etching resist, etc. are removed, and thereafter, a buffer layer 247 of SiO_2 or the like is formed all over the optical waveguide layer 223, that is, the optical waveguides 244 and 245, by sputtering or the like, and over the same, across the first optical waveguide 244 formed on the principal plane of the wafer 230 as well as the branches 245A and 245B of the second optical waveguide 245 formed on both the inclined planes 241A and 241B in the groove 243, a conductive layer 248 of a metallic layer of Al or the like or an amorphous Si layer or the like is formed by full-evaporation by CVD or the like and patterning by photolithography, or the like. By so doing, at the portion where the conductive layer 248 is deposited, first to third metal-clad type mode filters 249, 250 and 251 are formed for the optical waveguide 244 and the branches 245A and 245B of the optical waveguide 245.

As shown in Figure 22A5, a thin-film layer 222 constituting a recording magnetic head is formed between the fourth and fifth photodetector devices 234 and 235 over the end of the optical waveguide layer 223 constituting the optical playback head, or, in concrete terms, over the ends of the optical waveguides 244 and 245 for light beams. That is, a first magnetic thin film 252 is formed in a band form parallel to the short side of the area 228, and over the same, a head coil 254 of a conductive layer magnetic head in, for example a spiral pattern is formed by patterning by metallic layer evaporation and photolithography, or the like, with an interlayer insulating layer 253 of SiO_2 or the like interposed therebetween. Further, over the same, an insulating layer 255 of SiO_2 or the like is formed, a window 256 is opened in the insulating layers 255 and 253, for example, at the centre of the coil 254, and a second magnetic thin film 257 is formed, through this window, along the first magnetic thin film 252 in contact with a portion thereof. Thus, a closed magnetic circuit is formed of both the magnetic thin films 252 and 257, and thereby a thin-film magnetic head is structured, having the operating magnetic gap g at its front end using, for example, the insulating layer 253 as the gap spacer. Figure 20 shows an enlarged plan view of the magnetic head portion. While making contact windows by selective etching in the insulating layers covering the terminal areas 237 as well as the pad portions 238 and 239 so that they are exposed to the outside, contact windows for exposing both ends of the coil 254 are made, and wiring conductive layers 258 are formed, through the contact windows, between the ends of the coil 254 and the corresponding terminal areas 237, and thereby electrical leading out of the coil terminals is achieved.

Further, as shown in Figure 22A6, at the bent portions of the optical waveguides 244 and 245 where they are bent from their courses parallel to the short side of the area 228 to the courses parallel to the long side, there are formed prisms 259 and 260 by selectively etching the laminated insulating layer, buffer layer, or the like, so that prisms of an air layer are formed therein, or, as required, by burying a material with a low refractive index therein.

Now, an example of steps of procedure for constructing the apparatus by integrating the silicon wafer 230, having the head assembly formed of the magnetic head and optical playback head laminated thereon as described above, with a slider 31 will be described with reference to Figure 23.

In this procedure, a slider substrate 271, a ceramic substrate of Ti-Ca, Ti-Ba, AlTiC, ferrite, or the like, to be finally turned into sliders 31 as shown in Figure 23A is first prepared.

The principal plane of the substrate is finished to provide a smooth surface, and onto this surface, a wafer, for example, a monocrystalline wafer 230, having a plurality of the above described head assemblies thereon as shown in Figure 23B, is adhered by adhesive, glass bonding, molten metal bonding, or the like, whereby a joined member 272 is obtained.

Then, the joined member 272, including the head forming areas 228 having head assemblies therein of the silicon wafer 230, is separated by, for example, being cut along the boundaries between the rows in the longitudinal direction as shown in Figure 23C, so that blocks 273 each thereof having integrated plural sets of the head portion and slider portion are obtained.

In the surface adjoining the surface with the silicon wafer 230 joined thereto and lying on the side of the long side 228C of the area 228, where the front ends of the magnetic head and the optical playback head look out as described in Figure 22, there are cut a plurality of grooves 274, as shown in Figure 23D, in the direction perpendicular to the wafer 230 and parallel with each other. The groove is cut virtually in the centre of the long side 228C of each of the head forming areas 228 of each semiconductor wafer 230.

Meanwhile, as shown in Figure 23E, the portions of the block 273 between the grooves 274 on the side opposite to the side where the wafer 230 is joined are provided with a taper 275 by being cut and ground.

Then, as shown in Figure 23F, the block 273 is chip cut into a division having one area 228 of the wafer 230, whereby the substrate 221 having the head assembly is cut out together with the slider 31 to provide a slider member 276 being, for example, 3 mm wide and 1 mm high. The side of the long side 228C of the slider member 276 is ground so that it is formed into the confronting surface 81 to confront

the magnetic recording medium.

As shown in Figure 18, a semiconductor laser 277 is bonded onto the die bonding pad portion 238 for the laser diode and one electrode of the laser diode 277 is bonded using a wire lead 278 to the wire bonding pad portion 239. Thereupon, the attached portion of the semiconductor laser is sealed with a resin, and the member is arranged at the free end of the resilient member 25 of the gimbal mechanism described in Figure 3. In making such arrangement, a metallic plate 62 having a protrusion 61 on its top surface, for example, is attached to the slider member 276 so that the free end of the resilient plate 25 comes into abutment with the protrusion 61 allowing the slider member 276 to swing about the resilient plate 25. The terminal areas re soldered with external leads, for example, corresponding wires of a flexible substrate 79. In this way, the head apparatus can be constructed.

The terminals on the ground side of the apparatus of the first to fifth photodetector devices 231 to 235 and the semiconductor laser 277 are brought in common on the side of the substrate 221 (Si wafer 230) and the terminal lead is taken out from one terminal area 237 in contact with the substrate 221.

Outputs of the second and third photodetector devices 232 and 233 are supplied to a differential amplifier 135, and a differential output is derived. For the height of the semiconductor laser 277, in order that its light emitting end, that is, the end plane of its active layer, looks straight at the light inlet end of the first optical waveguide 244, provision is made, for example, to make a recess for its setting portion in the silicon wafer 230, or to adjust the thickness of the die bonding pad portion 238. The first photodetector device 231 is placed, for example, in a relative position with the semiconductor laser 277 such that it can effectively receive a beam of light which is similarly emitted from the semiconductor laser 277 facing the first optical waveguide 244, and the semiconductor laser 277 is arranged to be controlled for its power by the first photodetector devices 231.

The fourth and fifth photodetector devices 234 and 235 having their front ends looking out of the confronting surface 281 confronting the magnetic recording medium are arranged to receive reflected beams from track guide grooves (not shown) formed on the magneto-optical recording medium 31 for taking out a differential output thereof, thereby to perform tracking servo.

The first mode filter 249 is formed, for example, to lie along the surface of the substrate 221, whereby its plane of polarization is arranged at an angle of 90° with the centre plane between the inclined planes 241A and 241B for the second and third mode filters 250 and 251, that is, the centre of the planes of polarization of the second and third mode filters 250 and 251.

The magnetic recording and optical playback head constructed integrally with the slider member 276 disposed at the free end of the gimbal, that is, the resilient member 25, as described above, performs recording and playback in its floated state caused by an air flow produced by the relative movement of it with the magnetic recording medium 31, for example, a magneto-optical disc, as shown in Figure 3.

In its recording operation, magnetic recording in a magnetic recording medium is executed by an operation to be ordinarily performed by an induction-type head, that is, by being supplied with a signal current through the coil 254 of the thin-film magnetic head.

In its playback operation, light from the semiconductor laser 277 is introduced into the first optical waveguide 244 and passed through the first clad type mode filter 249, so that the light is turned into polarized light having a plane of polarization in a predetermined direction to be thrown on a recording track of the magnetic recording medium 31. Reflected light in which the plane of polarization has experienced a rotation by the magneto-optical interaction corresponding to the magnetically recorded information along the track is introduced into the trunk 245c of the optical waveguide 245. If a setting has been made such that, when, for example, the recorded information is "0" and therefore there is no rotation made in the reflected light, the output of the differential amplifier 135 will become, for example, zero upon receipt of the beams of light passed through the clad type mode filters 250 and 251 for the first and second branches 244A and 244B of the optical waveguide 244 into which the reflected light was introduced, then, when information "1" is read and therefore the reflected light experiences a Kerr rotation, one of the transmitted light quantities will increase while the other decreases, because the planes of polarization of both the second and third mode filters 250 and 251 are controlled by the inclined planes 241A and 241B in the opposite directions with respect to the plane at an angle of 90° with the plane of polarization of the clad type mode filter 249 for the first optical waveguide 244, and thus, a large output can be taken out of the differential amplifier 135.

As described above, in playback, light from the first optical waveguide 244 is thrown on the recording track of the magnetic recording medium 31. At this time, by selecting the section of the emitting end of the optical waveguide to be an elongated spot such as an elongated circular shape, or an elliptical shape, the laser beam spot on the recording track is arranged to be an elongated spot having its major axis in the direction of the width of the track as described in Figure 24. While Figures 24 and 25A both schematically show the pattern of the information bits formed by magnetization along the recording track on the magnetic recording medium, and the track width W is, for example, 1 to 2 μm and the bit length L_B is 0.5 to 1 μm, the relative spot of irradiation beam is made, as shown by the solid line a, to have a length φ_L in the major axis, corresponding to the track width T_W, in the lateral direction to the track, and a length φ_S in the minor axis in the direction longitudinal to the track.

In the case of optical record reading with an ordinary optical playback head, the spot is selected to be a virtually perfect circular shape as described above. In such a case, if the spot diameter is made to

be as large as corresponding to the track width Tw as shown by the broken line b in Figure 25A, the spot falls on adjoining bits, so that the output waveform exhibits a rounding as shown by the broken line b in Figure 25B and the S/N ratio is deteriorated especially in the short-wave range. If the spot diameter is made small as shown by the broken line c in Figure 25A, while the S/N ratio is improved, the output is lowered as shown by the broken line c in Figure 25B because the radiation of light is made only on a part of the bit. In contrast, since the beam spot is made into an elongated spot a as described above, the lowering of the output can be suppressed as shown by the solid line a in Figure 25B and the S/N ratio in the short-wave range can be improved.

The curves 291a, 291b and 291c in Figure 26 shown frequency characteristics of the spots a, b and c described in Figure 25.

When the spot in an elongated shape is used as described above, it is desired to arrange the first optical waveguide 244 to be able to propagate a basic wave mode, so that separation of the spot may be prevented from occurring and a single spot may be obtained.

With the optical playback head of the present invention, the optical system has been made smaller by the use of the optical waveguides instead of a conventional large lens system, and for the head for use with magneto-optical discs, the polarizer and analyzer have been arranged by the use of metal-clad mode filters, and hence, the head can be formed on a light-weight slider. Thus, high-speed access and high-density track formation can be attained.

Since the metal-clad mode filters are provided for the first and second optical waveguides and they are arranged to form an angle of 45° or a predetermined angle close to 45° with each other, the playback signal from a magneto-optical disc can be maximized.

Since the ends of the first and second optical waveguides are disposed adjacent to each other and the sectional area of one end of the second waveguide is formed to be larger than the sectional area of one end of the first optical waveguide, it is possible effectively to collect the reflected light from a recording medium through the end of the second optical waveguide and thereby to enhance the playback output greatly.

Since the sectional area of one end of the first optical waveguide is formed to be small, the return light of the reflected light to the first optical waveguide is limited, whereby unstable oscillation of the laser diode is prevented.

Since the sectional area of one end of the first optical waveguide is made small, formation of narrower recording tracks can be attained. Moreover, since the optical system can be made smaller by the use of the optical waveguides instead of a large lens system, the pick-up can be formed on a light-weight slider and high-speed access can thereby be attained.

Since the design for an integral structure laminating a thin-film magnetic recording head and an optical playback head of an optical integrated circuit on a common semiconductor substrate is adopted, the positioning of both the heads can be carried out accurately, and since the thin-film technique capable of forming the film with high precision is used, the positioning can be made more accurate, and mass production with good reproducibility can be attained. Further, since the device can be structured in small size and light weight, the head as a whole can be light. Hence, high-speed access can be attained.

Moreover, in a particular structure, the optical waveguides of the optical waveguides 244 and 245 are all provided with mode filters 249, 250 and 251 in their midpoints, and this means that such a structure generally requires considerably dimensions. But, by employing the prisms 259 and 260, it is possible to stretch the waveguides 244 and 245 not only in the direction of the height of the slider 33, but also in the direction turned from that direction parallel to the magnetic recording medium 31. As a result, the need for holding the slider 33 high, and hence, the need for keeping the point of support of the gimbal, that is, the resilient member 25 high, is eliminated, and thus, it is possible to overcome the structural disadvantage involved therein.

Moreover, since the output from the optical playback head is taken out as a differential value of the outputs from both the branches 245A and 245B, an increased output level is obtained and the noise components being in phase are cancelled by each other, so an improved S/N ratio can be achieved.

While, in obtaining such a differential output, there must be provided first and second branches 245A and 245B and the mode filters 250 and 251 must be provided, the branches 245A and 245B together with the first optical waveguide 244 are stretched in the two directions relative to the magnetic recording medium 31 as described above. As a result, it becomes possible to arranged these three members side by side and, hence, to form a common conductive layer 248 across the three members, enabling the three mode filters 249, 250 and 251 to be formed at the same time. Thus, the fabrication can be made easier and the structure can be made simpler.

Claims

1. A magneto-optical playback head comprising:

a first optical waveguide (38) facing a light source (36) at one end thereof and facing a magneto-optical recording medium (31) at another end thereof for guiding an incident light beam to said recording medium (31);

a second optical waveguide (40) for guiding a light beam reflected from said recording medium (31) to a photodetector (33) provided at one end thereof;

a polarizer (46) for said first optical waveguide (38); and

an analyzer (47) for said second optical waveguide (40), said polarizer (46) and said analyzer (47) being formed by providing first and second conductive layers (50, 51) on said first and

second optical waveguides (38, 40), with first and second insulating buffer layers (48, 49) interposed therebetween, respectively.

2. A magneto-optical playback head according to claim 1 wherein said first and said second conductive layers (50, 51) are arranged at a predetermined angle with each other.

3. A magneto-optical playback head according to claim 2 wherein said predetermined angle is substantially 45°.

4. A magneto-optical playback head according to claim 1 wherein said second optical waveguide (40) is arranged to face said recording medium (31) at the other end thereof, aligned to substantially the same portion of said recording medium (31) as that to which said first optical waveguide (38) is aligned.

5. A magneto-optical playback head according to claim 4 wherein said second optical waveguide (40) has an opening at said other end which is larger than an opening at said other end of said first optical waveguide (38).

6. A magneto-optical playback head according to claim 1 wherein said first and second optical waveguides (38, 40) are formed into a common structure at said other ends facing said recording medium (31).

7. A magneto-optical playback head according to claim 1 wherein said conductive layers (50, 51) are formed of aluminium.

8. A magneto-optical playback head according to claim 1 wherein said conductive layers (50, 51) are formed of amorphous silicon.

9. A magneto-optical playback head according to claim 1 wherein said first and second optical waveguides (38, 40) are coupled optically by a directional coupler (39).

10. A magneto-optical playback head comprising:
a first optical waveguide (121A) coupled to a light source (118) at one end thereof and facing a magneto-optical recording medium (31) at another end thereof for guiding an incident light beam to said recording medium (31);
a second optical waveguide (121B) for guiding a reflected light beam from said recording medium (31), said second optical waveguide (121B) being formed of a first waveguide portion (121B1) and a second waveguide portion (121B2), and one end of each of said first and second waveguide portions (121B1, 121B2) being provided with respective first and second photodetectors (119, 120), respectively;
a polarizer (123) for said first optical waveguide (121A); and
first and second analyzers (124, 125) for said first and second waveguide portions (121B1, 121B2) formed by providing first, second, and third conductive layers (129, 130, 131) on said first optical waveguide (121A) and said first and second waveguide portions (121B1, 121B2), respectively, with insulating buffer layers (126, 127, 128) interposed therebetween.

11. A magneto-optical playback head according to claim 10 wherein an output signal is derived from said first and second photodetectors (119, 120) differentially.

12. A magneto-optical playback head according to claim 10 wherein said second conductive layer (130) of said first analyzer (124) and said third conductive layer (131) of said second analyzer (125) are inclined at first and second angles, respectively, with respect to a reference plane defined by said first conductive layer (129) of said polarizer (123).

13. A magneto-optical playback head according to claim 10 wherein said polarizer (123), and said analyzers (124, 125) each operate as a TE mode pass filter or a TM mode pass filter.

14. A magneto-optical playback head according to claim 13 wherein said first and second analyzers (124, 125) operate as TE mode pass filters.

15. A magneto-optical playback head according to claim 14 wherein optical outputs of light beams to be detected at said first and second photodetectors (119, 120) change oppositely to each other when light beams having the same change in the rotation angle of polarization are passed through said first and second analyzers (124, 125).

16. A magnetic recording and magneto-optical playback head comprising:
a magneto-optical playback head according to any one of claims 1 to 15; and
a thin-film magnetic recording head (222) disposed adjacent to said magneto-optical playback head, said thin-film magnetic recording head (222) and said magneto-optical playback head being provided on a common substrate (221).

17. A magnetic recording and magnetic-optical playback head according to claim 16 wherein said heads are formed on a common slider (276).

18. A magnetic-optical playback head according to claim 1 or claim 10 wherein said first optical waveguide (38, 121A) forms an elliptical spot on said recording medium (31) such that the larger diameter of said elliptical spot is aligned with the width of a recording track on said recording medium (31).

19. A magneto-optical playback head according to claim 10 wherein said first and second waveguide portions (121B1, 121B2) are arranged to be partially parallel to a surface of said recording medium (31).

20. A magneto-optical playback head according to claim 10 wherein said first and second waveguide portions (121B1, 121B2) are bent to bring said waveguide portions (121B1, 121B2) substantially parallel to a surface of said recording medium (31).

FIG. 1

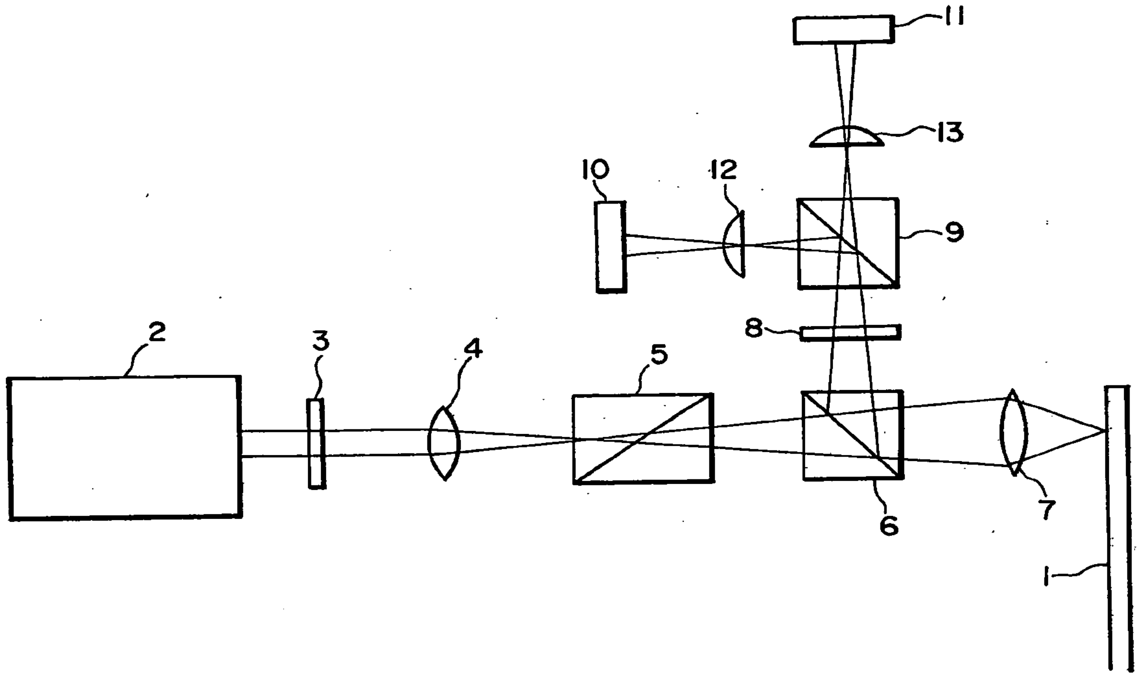


FIG. 2

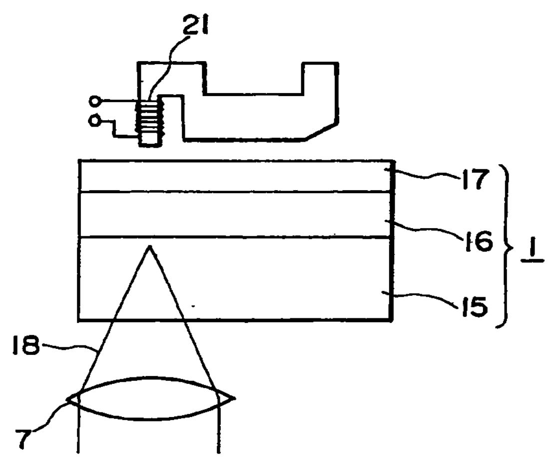


FIG. 3

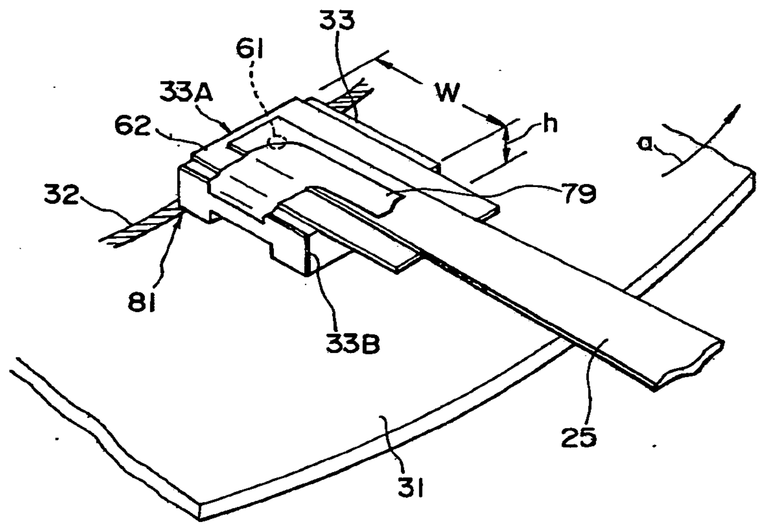


FIG. 4

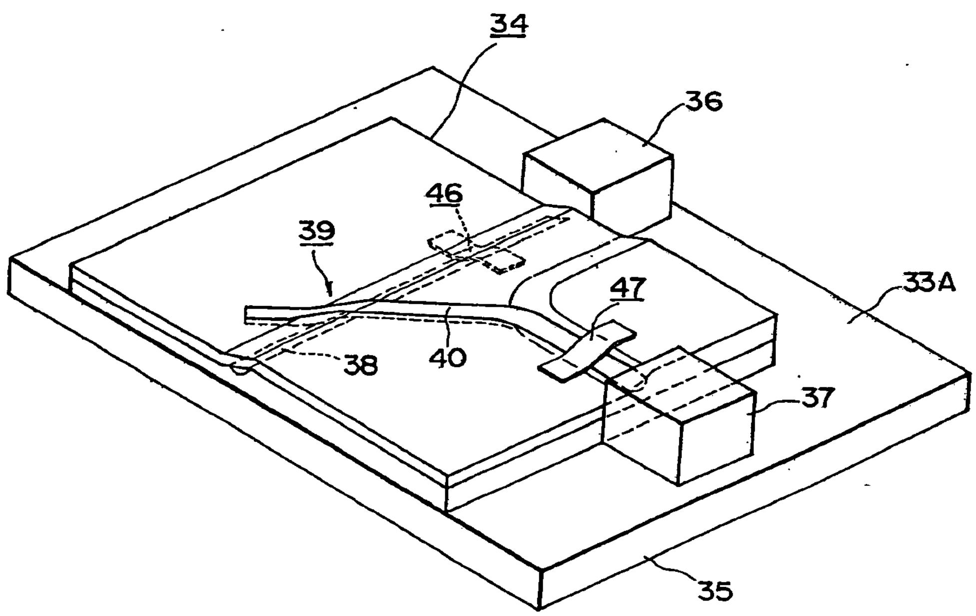


FIG. 5

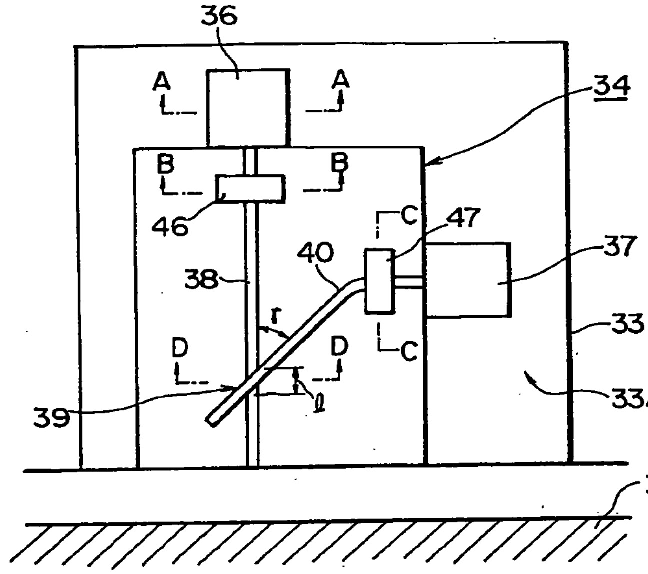


FIG. 6A

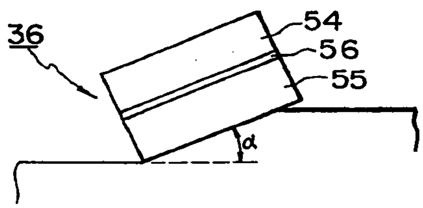


FIG. 6B

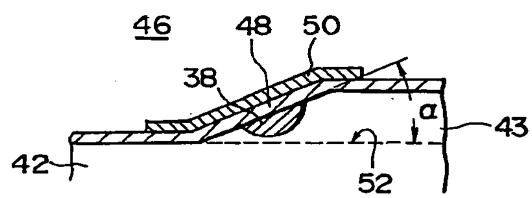


FIG. 6C

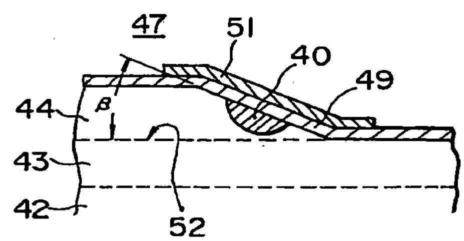


FIG. 6D

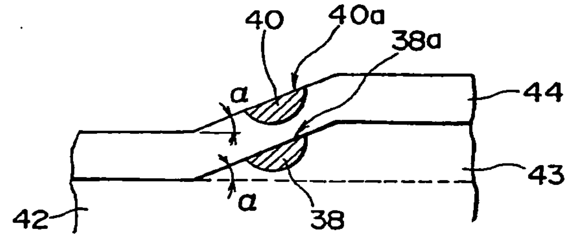


FIG. 7

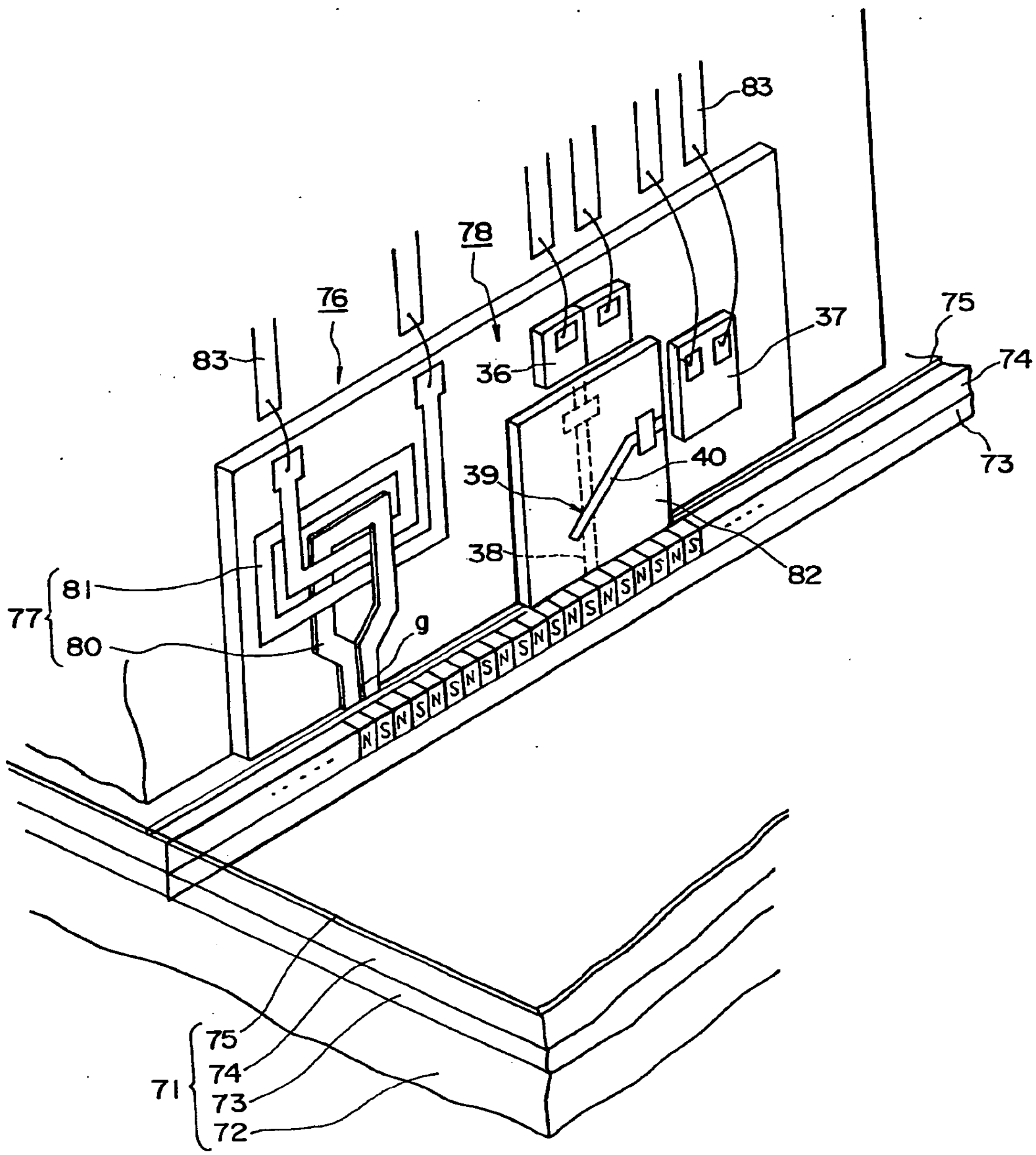


FIG. 8

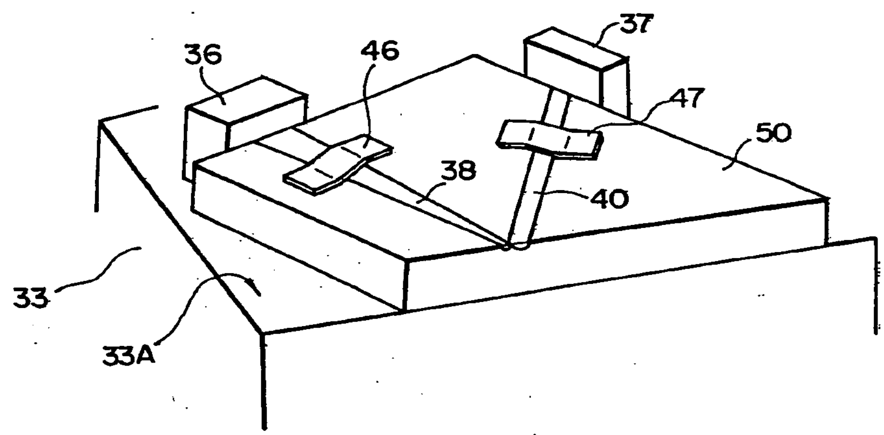


FIG. 9

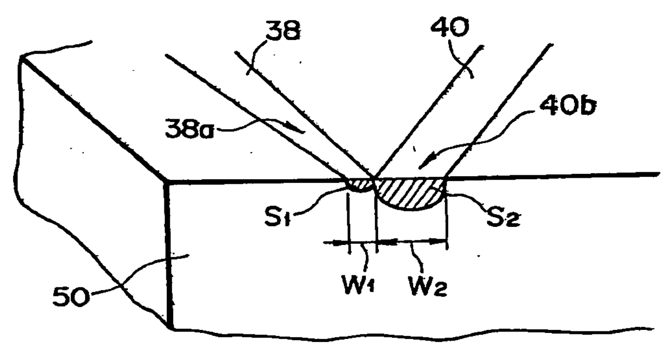


FIG. 10A

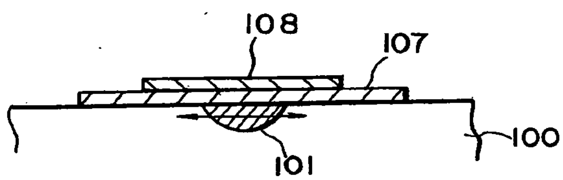


FIG. 10B

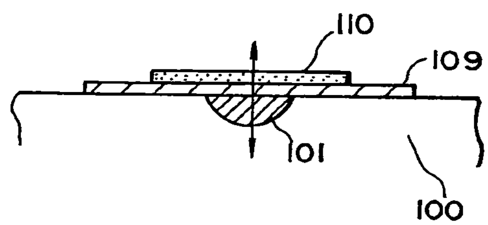


FIG. 11A

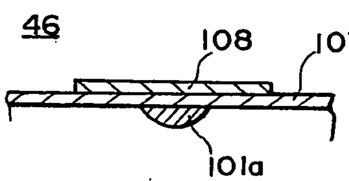


FIG. 11B

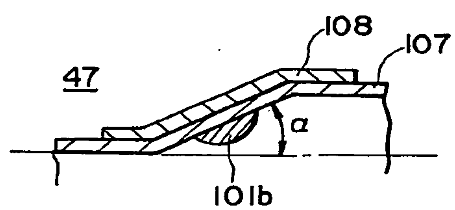


FIG. 12A

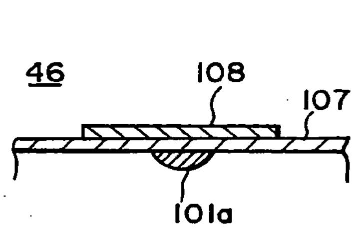


FIG. 12B

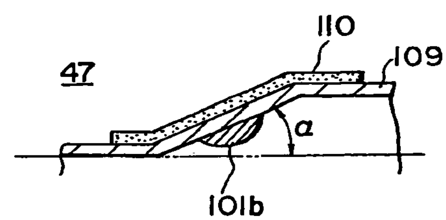


FIG. 13

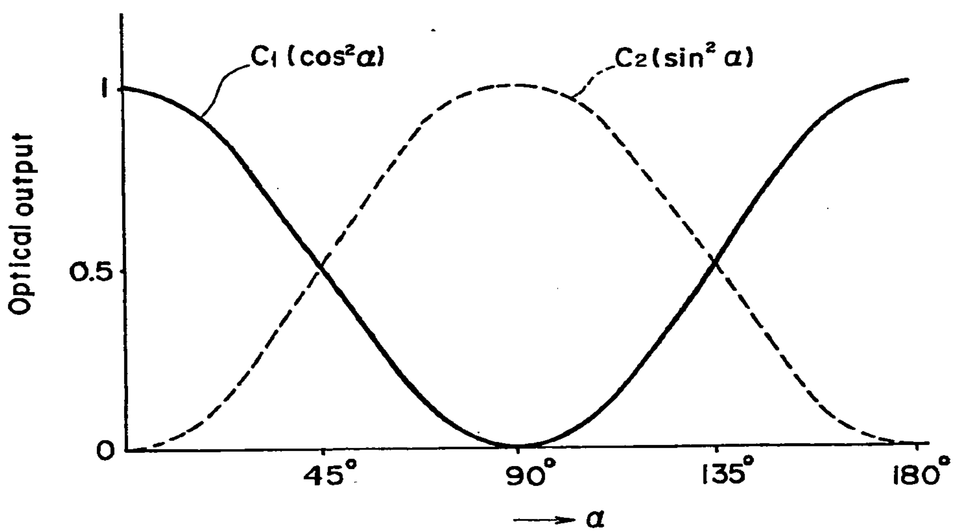


FIG. 14

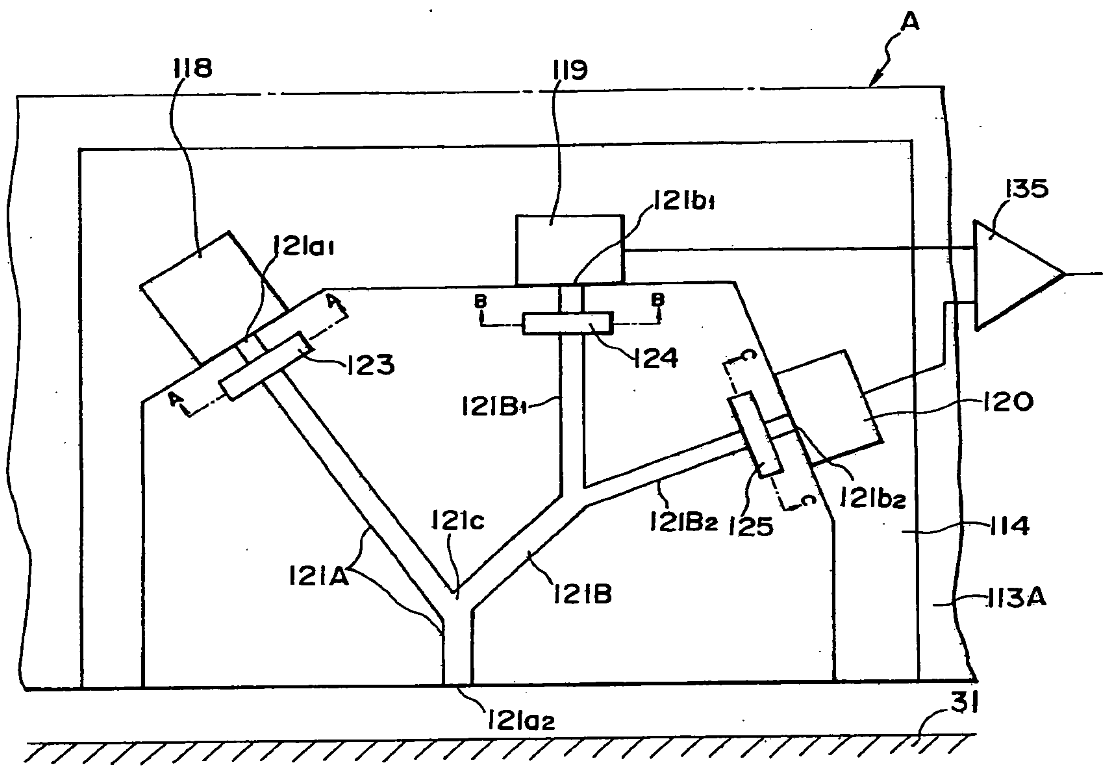

A
118
119
121b1
135
121a1
B
B
123
124
120
121B1
121b2
121B2
125
114
121c
121A
121B
113A
121a2
31

FIG.15A

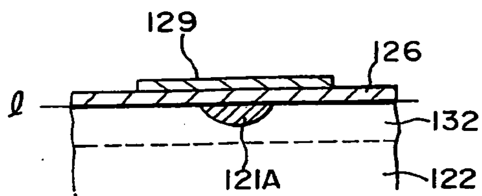


FIG.15B

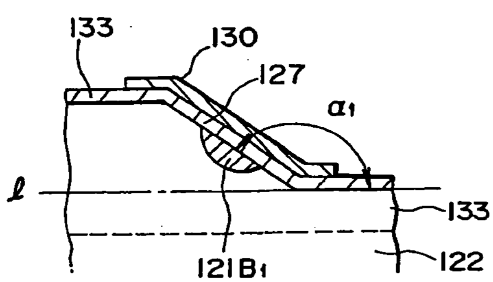


FIG.15C

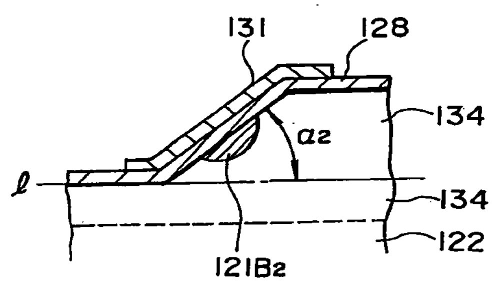


FIG. 16A1

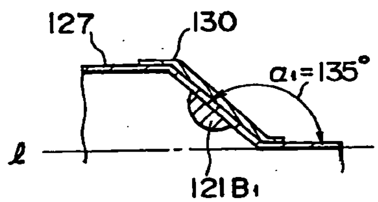


FIG. 16A2

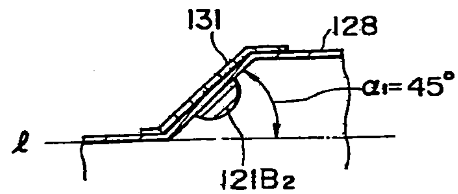


FIG. 16B1

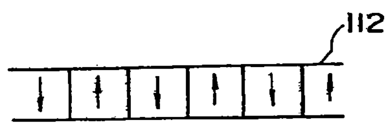


FIG. 16B2

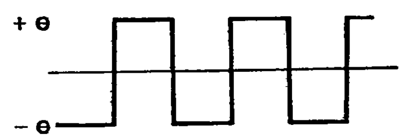


FIG. 16C1

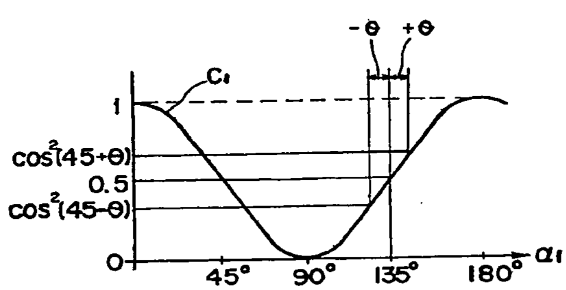


FIG. 16C2

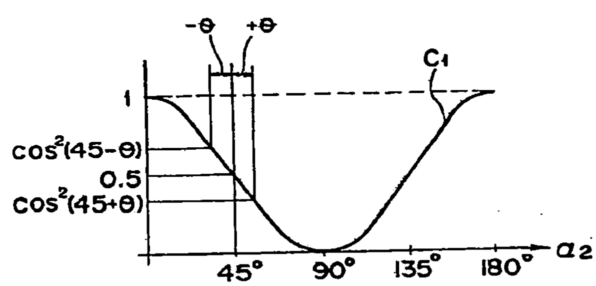


FIG.16D1

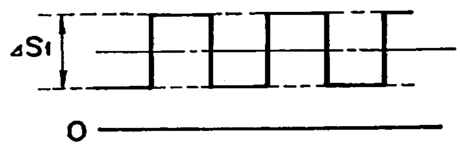


FIG.16D2

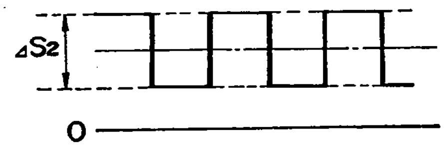


FIG.16E

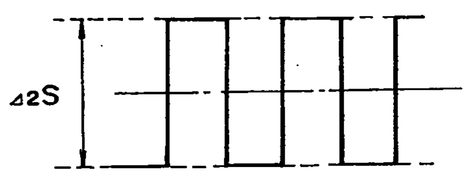


FIG.17A1

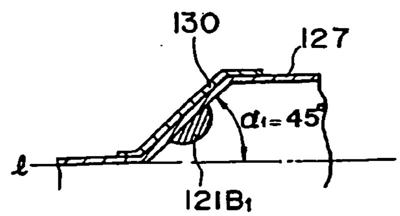


FIG.17A2

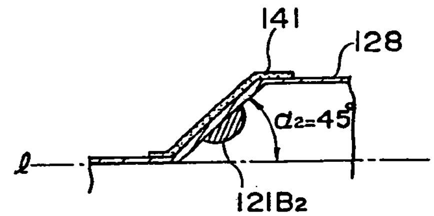


FIG.17B1

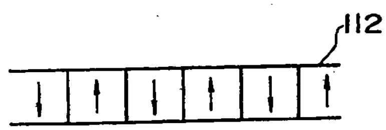


FIG.17B2

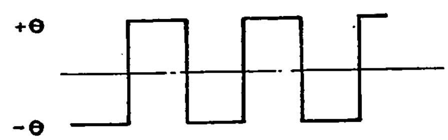


FIG.17C1

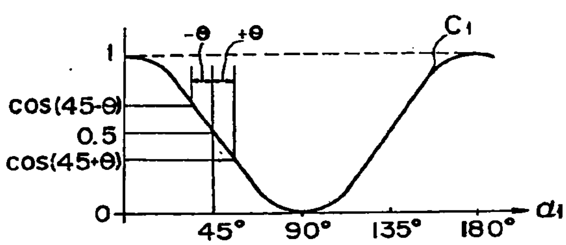


FIG.17C2

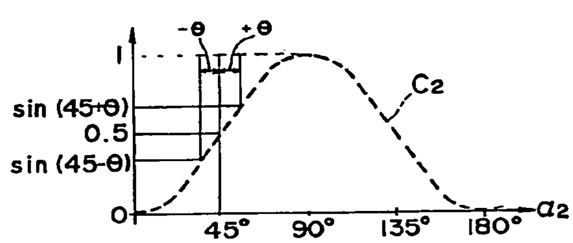


FIG. 17D1

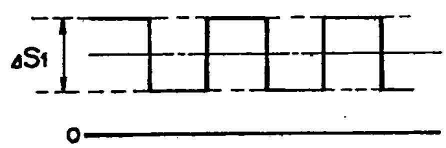


FIG. 17D2

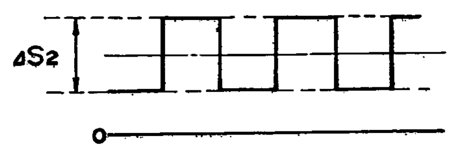


FIG. 17E

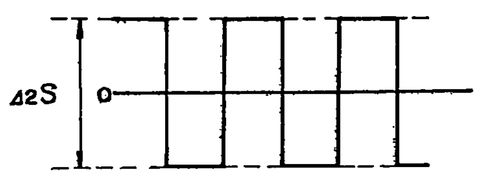


FIG. 18

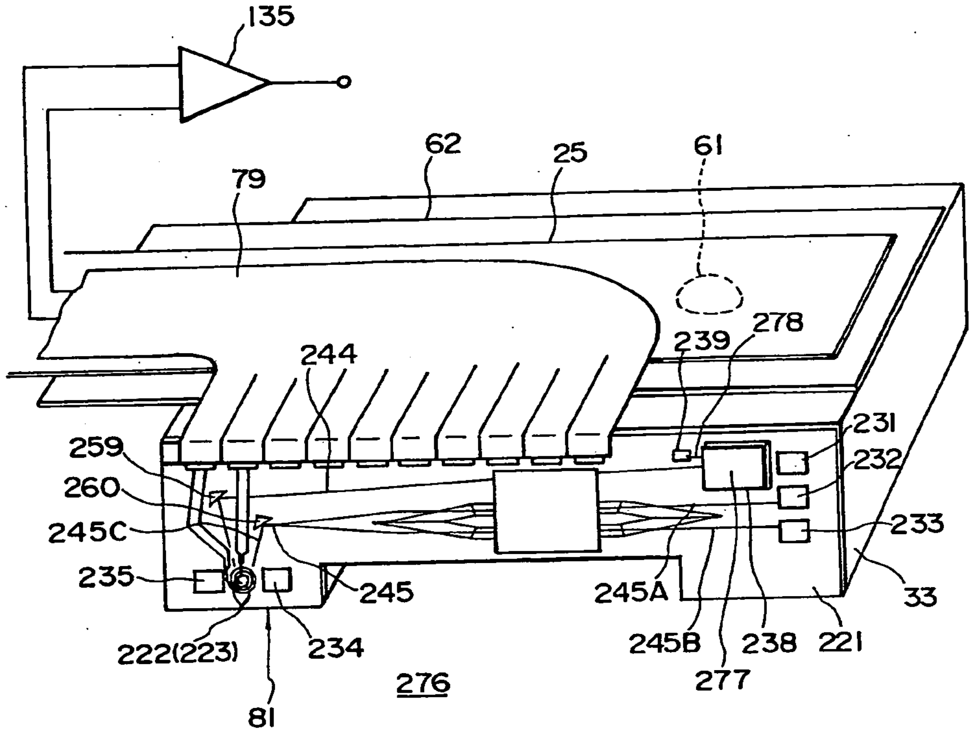

135
62
25
61
79
239
278
244
231
259
232
260
245C
233
235
245
245A
33
222(223)
234
245B
238
221
276
277
81

FIG. 24

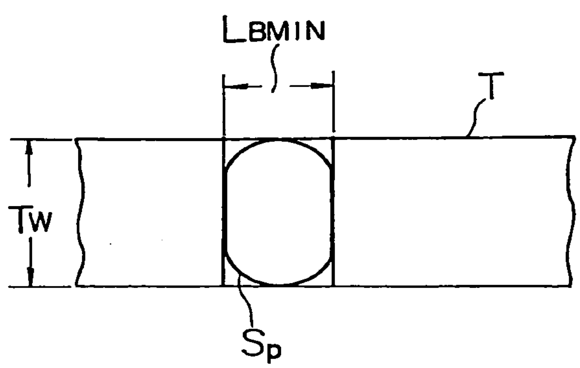

LBMIN
T
Tw
Sp

FIG. 19

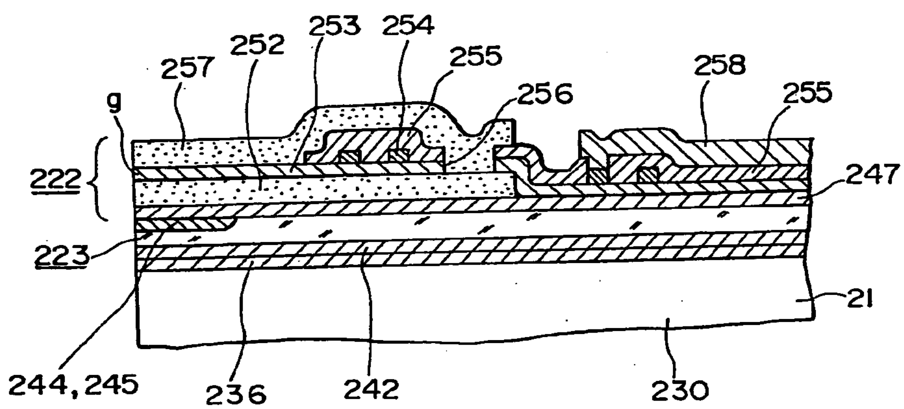


FIG. 20

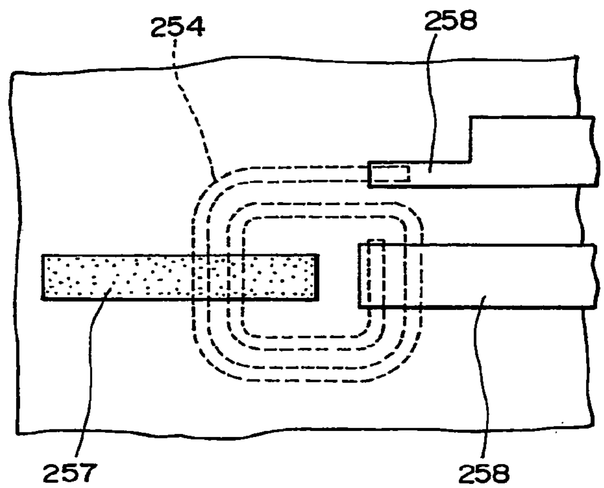


FIG. 21

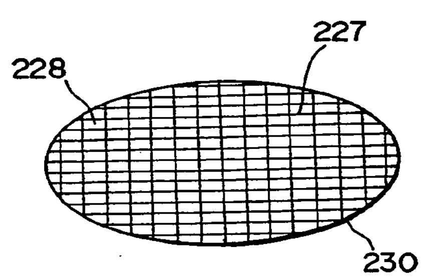


FIG. 22A1

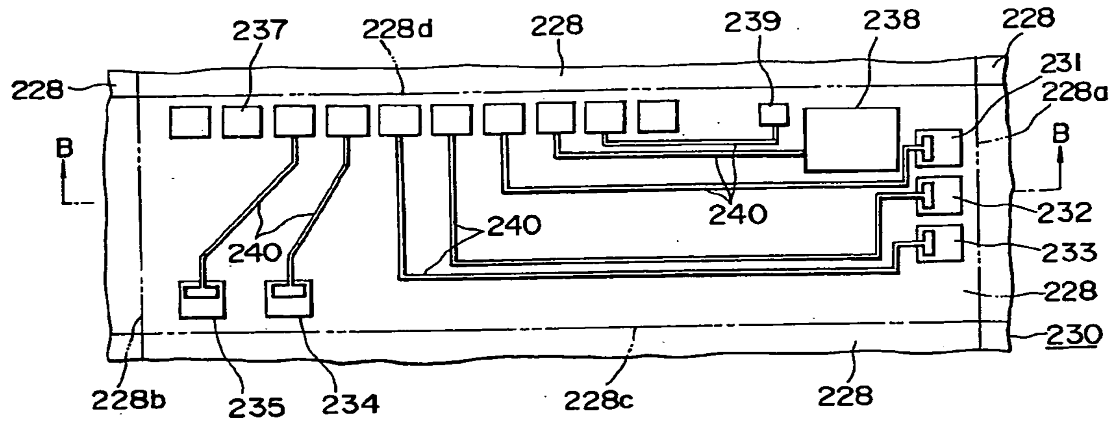


FIG. 22B1

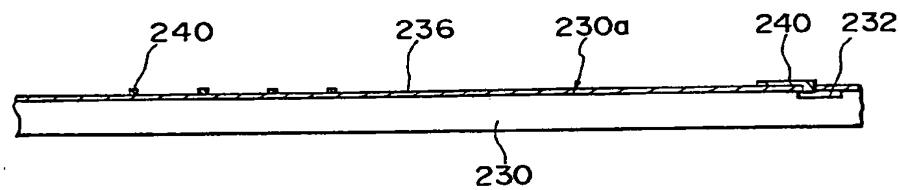


FIG. 22A2

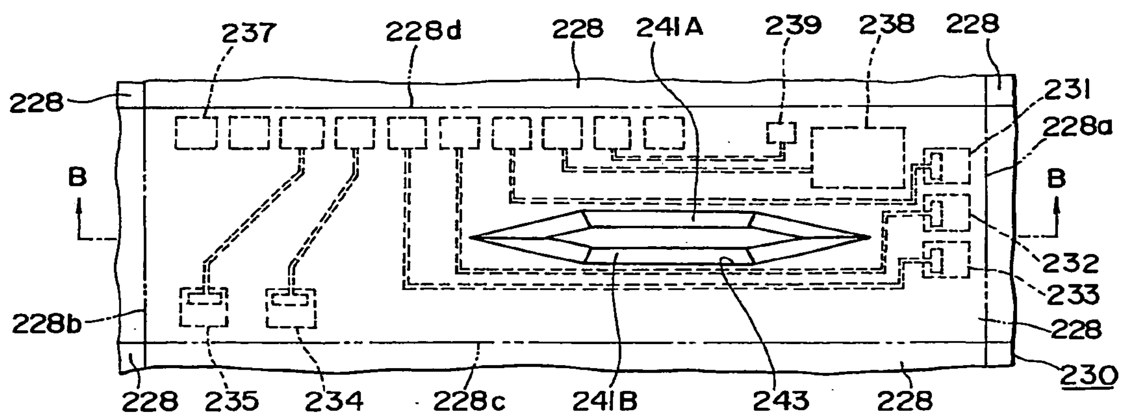


FIG. 22B2

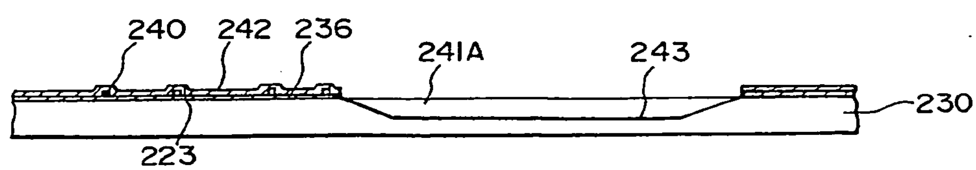


FIG. 22A3

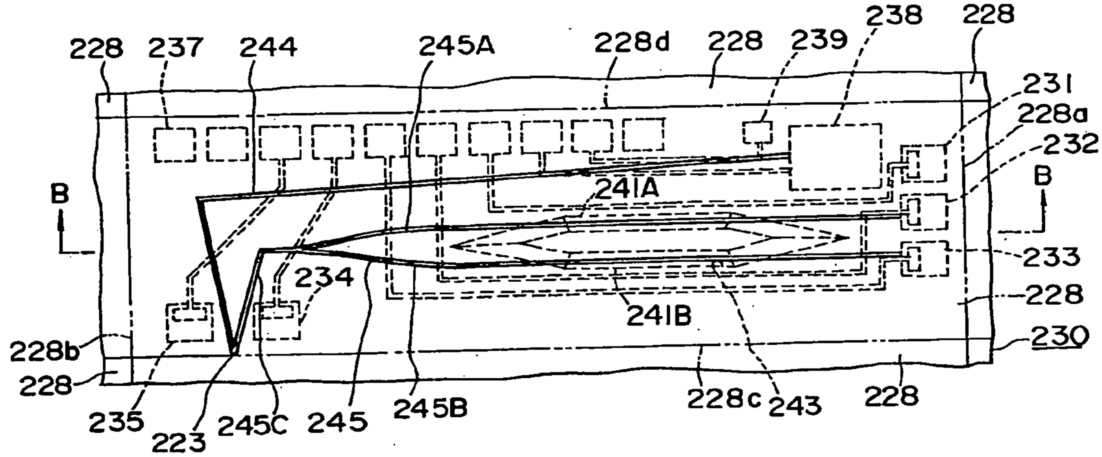


FIG. 22B3

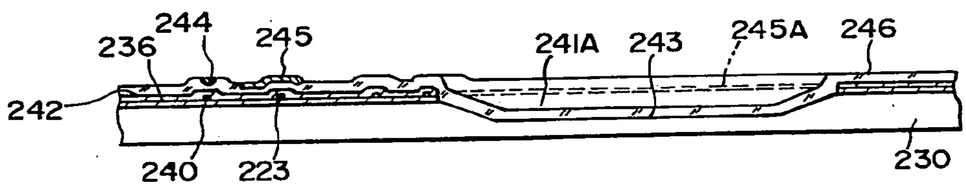


FIG. 22A4

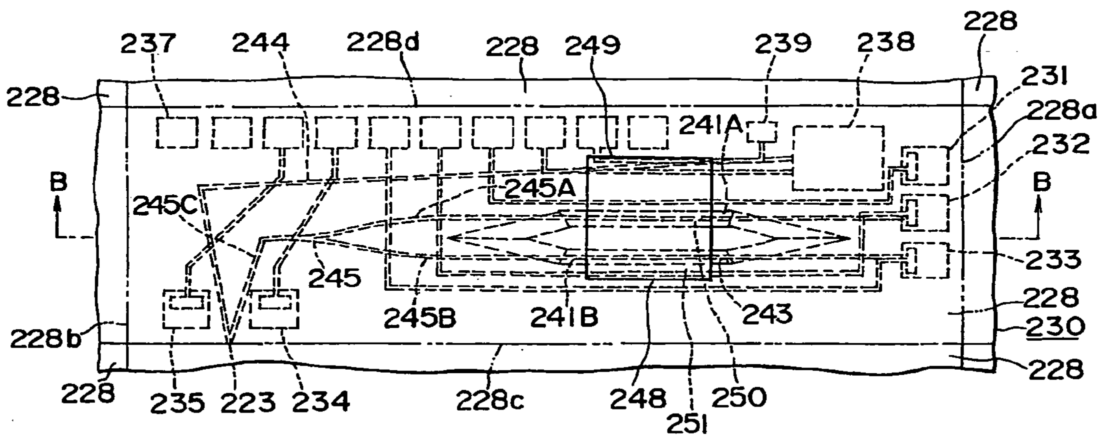


FIG. 22B4

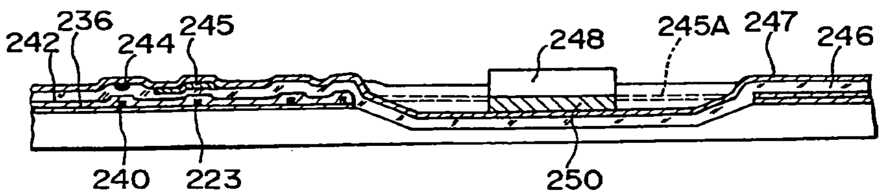


FIG. 22A5

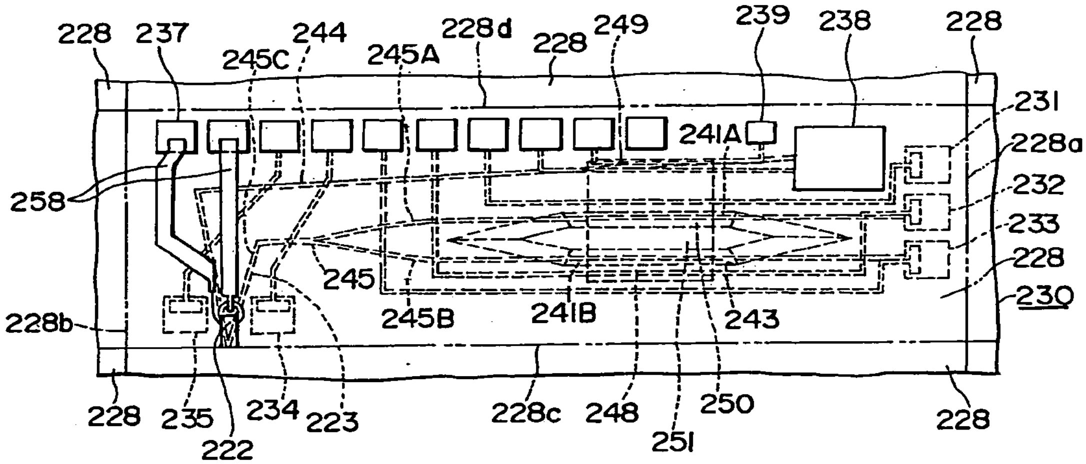


FIG. 22A6

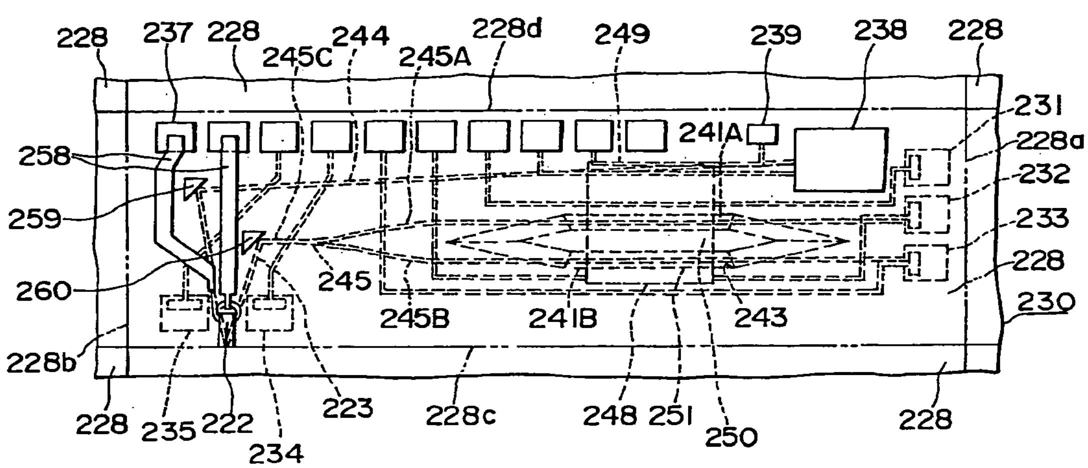


FIG. 23A

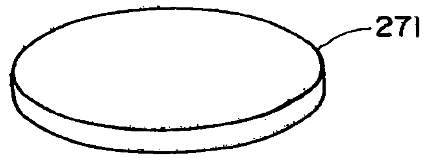


FIG. 23B

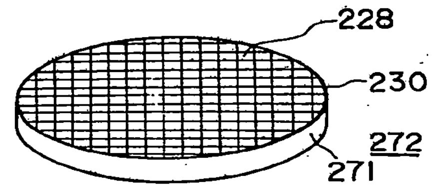


FIG. 23C

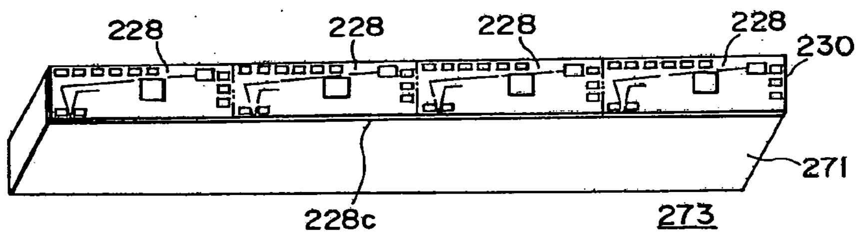


FIG. 23D

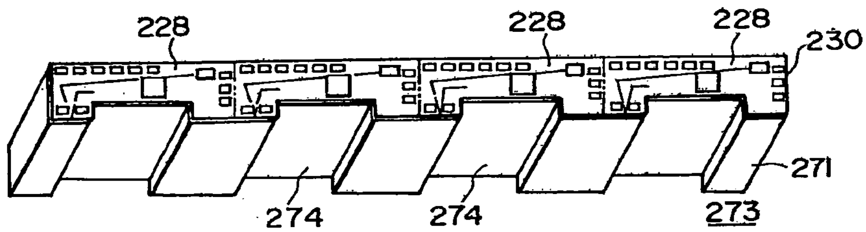


FIG. 23E

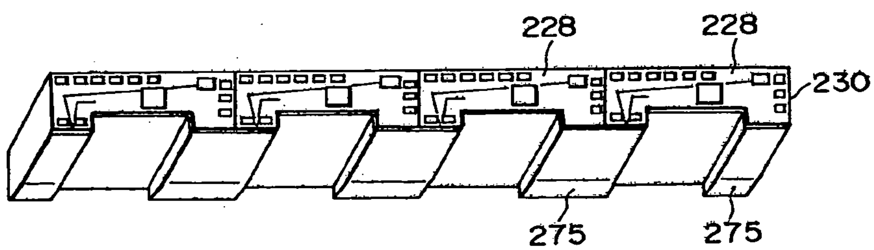


FIG. 23F

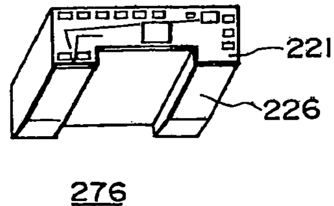


FIG.25A

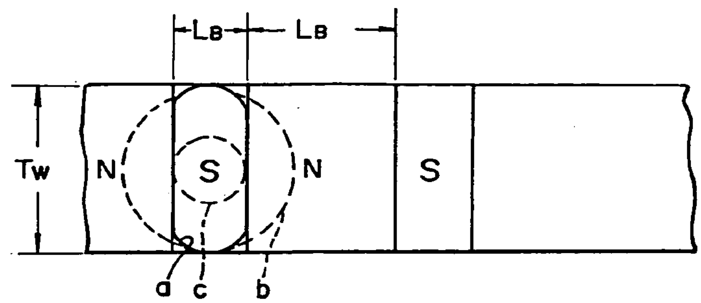


FIG.25B

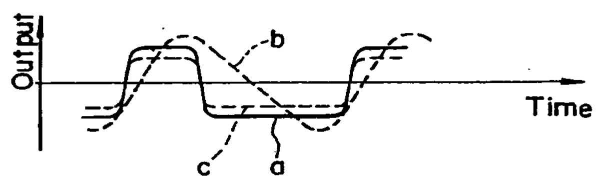


FIG. 26

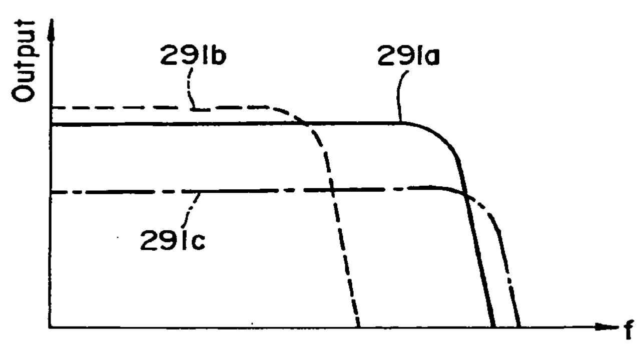


FIG. 27A

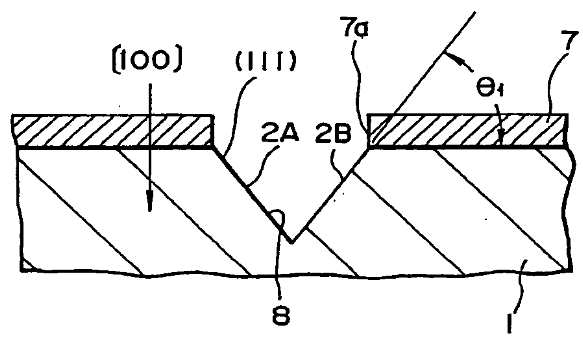


FIG. 27B